REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	22.Apr.99	DISSERTATION

4. TITLE AND SUBTITLE
INHALATION EXPOSURE RISK DURING A MILITARY OPERATION: A RISK ASSESSMENT APPROACH

5. FUNDING NUMBERS

6. AUTHOR(S)
MAJ RUSCIO BRUCE A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
JOHNS HOPKINS UNIVERSITY

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CIA, BLDG 125
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
FY99-100

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited distribution
In Accordance With AFI 35-205/AFIT Sup 1

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

14. SUBJECT TERMS	15. NUMBER OF PAGES
	254
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

INHALATION EXPOSURE RISK DURING A MILITARY OPERATION: A RISK ASSESSMENT APPROACH

By

Bruce A. Ruscio

A dissertation submitted to The Johns Hopkins University in conformity with the requirements for the degree of Doctor of Public Health

Baltimore, Maryland
1999

Abstract

Risk management decisions are a military decision-maker's primary responsibility and are based on risk assessments characterizing the probability and severity of the potential mission effect. Military deployment environmental hazard tolerances are presently based on point estimates of exposure risks using regulatory standards. The goal of this research is the evaluation of deterministic and probabilistic techniques in assessing and characterizing deployment exposure risks.

This research estimated noncarcinogenic health risk from inhalation exposure to benzene during a military deployment, based on air monitoring conducted at 16 locations using U.S. Environmental Protection Agency (EPA) methods and guidelines. Ambient benzene concentrations -- 3.86 $\mu g/m^3$ (Tuzla), 8.27 $\mu g/m^3$ (1^{st} Brigade), and 1.1$\mu g/m^3$ (2^{nd} Brigade) -- were similar to U.S. urban areas. Hazard quotients derived using EPA's Reasonable Maximum Exposure (RME) procedures and Monte Carlo simulations for deployed occupational cohorts are compared. An RfD_i calculated by time-weighting EPA's reference concentration and the American Conference of Government Industrial Hygienists' Threshold Limit Value is proposed for military deployment risk assessment.

This research found that health risk estimates from exposure to ambient levels of benzene for military members deployed to the Former Yugoslavia are below levels of concern using EPA guidelines designed to protect the most sensitive subpopulations. Risk estimates are also below levels of concern using standards set for occupational workers. Point risk estimates and the mean and upper 95% of the probability distributions are below a hazard quotient level of 1.0.

Deterministic hazard quotients (RMEs) did not exceed the 95^{th} percentile of

simulation derived hazard quotient distributions using military-specific default values. The RME values are equivalent to Monte Carlo simulation averages using the EPA RfD_i. The upper 95^{th} percentile of hazard quotient distributions derived using the TLV- EPA RfD_i exceeded the RME values and are predictive of the simulations' means using the EPA RfD_i.

Deployed military populations can have significantly different environmental and receptor parameters due to physically demanding tasks, extended periods of activity, and extended periods of exposure. Hazard tolerance levels reflective of the deployment condition and the military work force should be adopted. Critical evaluation of exposure assessment techniques serves as a platform for development of an appropriate and consistent assessment program, and for development of preventive medicine policy that supports the military decision-maker and protects the member from unnecessary risk.

Probabilistic technique, effective in characterizing a deployment population's exposure risk, allows for effective integration of risk management into mission planning, preparation, and execution. Existing Department of Defense (DoD) environmental surveillance standards are based on environmental or occupational laws, policies, regulations, and standards established for the general population, the workforce, and Superfund environments. Blanket adoption of these guidelines is inappropriate for military deployments where populations live and work in the same environment, and where risk management considerations are different from those of peacetime.

Dedication

For my parents, Janet and Vincent Ruscio

Acknowledgements

I am fully indebted to my advisors, Dr. Thomas Burke and Dr. John Groopman, for their guidance, support, and leadership in expanding and shaping my ideas, views and understanding of environmental and public health, and health policy and politics. I would like to express my sincere appreciation to my research committee members: Drs. Timothy J. Buckley, Mike Foster, Harvey Ko, Charles Rohde, and Nga Tran for their invaluable advice, time, and knowledge.

I am very grateful to the following organizations and the outstanding professionals for the project facilitation:

U.S. Army 520th Theatre Army Medical Laboratory
U.S. Army Research Institute of Environmental Medicine
U.S. Army Center for Health Promotion and Preventive Medicine
Armed Forces Medical Intelligence Center
Human Exposure Assessment Branch, National Exposure Research Laboratory, Environmental Protection Agency

For their support, mentoring, advice, encouragement, and cheerleading along the way, I must thank Drs. Deborah and Scott Keimig, and Henry Gardner, Colonel Robert Landry, and Fred Brocker. Finally, I would like to thank my family: Renee, Henry, Leslie, Lauren, Lisa, Brian and Brad for helping me stay sane during the past several years.

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CHAPTER 1 INTRODUCTION

Risk assessment as described by the National Research Council (NRC) is the systematic characterization of potential adverse health effects resulting from human exposure to hazardous agents or situations (NRC, 1983). Risk assessment is a tool designed to help protect individual and community health by contribution to sound public health practices and better decision making. The end product is a qualitative and quantitative characterization of risk that incorporates a given exposure assessment and the relevant potential health effects based on hazard identification and dose-response information.

The NRC paradigm is being considered for the assessment of environmental health risks during U.S. military deployments. Application of the NRC paradigm for risk assessment from ambient chemical exposures during deployments is in response to, and recognition of, the need to characterize the full range and extent of military health risks. Department of Defense (DoD) Directive 6490.2, Joint Medical Surveillance, August 30, 1997, requires risk assessment, medical surveillance, and risk communication for all military deployments (DoD, 1997a). An effective deployment environmental health risk assessment strategy, which supports mission accomplishment and protects members' health, integrates a sound scientific approach into the DoD highest-level health policy directive -- Health Service Support Visions 2010 (HSSV 2010) (DOD 1997b).

Military deployment risk assessment presents challenges unlike many other situations where the NRC paradigm is applied. However, the underlying basic public health approach applies, and is applicable for guiding information collection pre-, during- and post-deployments, identification of intervention points, epidemiology strategies, and

the communication of risks to military members and decision makers.

Appropriately adapted for military deployment scenarios, the NRC risk assessment paradigm will strengthen military public health initiatives and help ensure force protection during deployments through the integration into the military risk management framework (DA, 1998). The NRC paradigm has the potential to guide the development of standardized data definitions and needs, collection, analysis, and methodologies for deployment exposure assessment. The evaluation of quantitative risk assessment techniques for military deployments will result in recommendations for medical surveillance implementation, deployment preventive medicine programs, and research and development requirements.

The Department of Defense (DOD) currently uses a deterministic or "single-point" risk estimate technique in the quantitative evaluation of exposure risks during military deployments. Deterministic techniques commonly estimate the upper bound of the risk distribution by using chosen default values believed to protect the most susceptible. For military operations, deterministic technique does not estimate the upper bound of the risk distribution, producing an estimate at an unknown point in the risk distribution.

The single point estimate from deterministic techniques does not fit the military risk management framework. The military risk management framework requires a risk characterization that includes the probability and severity of a potential loss/effect that may result from hazards due to an enemy, an adversary, or other hazardous condition (Department of the Army, 1998). The risk management framework explicitly does not "require a go/no-go decision" -- the risk assessment deterministic "bright-line" (Department of the Army, 1998).

Current application of the deterministic technique does not adequately characterize the deployed environmental exposure risks for several reasons. First, general population default values do not appropriately characterize the military population, military subpopulations, or the deployment environment. Secondly, deterministic techniques do not provide information about the level of uncertainty and variability in the final estimate of risk. Third, military decision-making is a comparative risk approach where distributions of risk are indispensable. Finally, existing preventive medicine environmental surveillance regulations, guidelines, and doctrine are based on or adapted from existing environmental laws, policies, regulations, and exposure standards established for U.S. citizens in an urban or Superfund type environment, or an occupational environment. The adoption of these environmental guidelines is inappropriate for deployments where clean up and remediation is not a primary risk management goal, and where living and working conditions are frequently very different from those of U.S. citizens and the workforce.

The U.S Environmental Protection Agency (EPA) default input values to deployment exposure risk estimates assume a susceptible subpopulation needing protection with physiological and behavioral distributions similar to those of the general U.S. population. These assumptions create obvious concerns in the level of uncertainty and conservatism they introduced in the risk estimate. Deployment living and working conditions is vastly different from those typical of EPA risk assessments. Also, the deployed military population is a healthy workforce, and exposure reference values designed to protect the general population may over estimate the level of risk. Risk estimates supportive of preventive medicine activities and needs of military decision-makers must present a characterization of the distribution of risk and uncertainties using

input parameters specific to deployment conditions, and military populations.

Probability analysis techniques offer a potential solution for the functional risk assessment needs of military deployments. Since the early 1990s, the application of probabilistic health risk assessment has been increasingly adopted (Hattis and Burmaster, 1994). A probabilistic method, described in detail below, is a distribution-based analysis offering the capability to describe the characteristics of the risk of military deployment exposures. The variety of deployed subpopulations, deployment specific activities and other parameter results in a range of possible exposure risks that need to be characterized. Evaluation of input parameters and risk estimates from probabilistic techniques provides insight and understanding into these exposure distributions. Use of probabilistic techniques provides preventive medicine practitioners and decision-makers with information on the distribution of risk and characterization of the uncertainties in the estimate. These factors are critical for the military decision-maker faced with competing risks. Environmental health risk assessment methodologies consistent with medical surveillance initiatives will serve as a foundation for the DoD preventive medicine policy, and doctrine development.

An evaluation of deterministic and probabilistic techniques serves as a platform for preventive medicine's development of appropriate and consistent exposure and risk assessment programs. It identifies opportunities to integrate environmental health assessments into medical surveillance activities, preventive medicine initiatives, and mission commander's goals during deployments. This research supports DoD military force health protection initiatives and suggests utilization of a probabilistic approach as an effective method to characterize further deployment exposure risk.

This research evaluates the application of the exposure assessment step of the

NRC paradigm for military deployments and proposes recommendations for enhancing the military's risk assessment and management capabilities. Exposure assessment, further defined below, evaluates the interaction of the human contact with pollutants in different media. Exposure assessment is an integral, but underdeveloped, component of deployment risk assessment. A deployment environmental risk assessment program will depend on quality of information obtained from an exposure surveillance activity. An effective approach to exposure assessment will provide preventive medicine capacity to assess deployment exposure risks to environmental contaminants, communicate the risk to the decision-maker, implement appropriate environmental and personnel surveillance, and assess potential adverse acute and delayed health outcomes. While the purpose is to ensure a more healthy military force, the knowledge obtained and techniques developed in exposure assessment during deployments has broad applications outside the DoD, throughout the field of environmental health.

1.1 Goals

The goal of this research was to evaluate a specific application of exposure assessment by comparing the noncancer hazard index level of a selected inhalation toxicant using U.S. population and military deployment input parameters in both deterministic and probabilistic techniques. Currently, deterministic techniques, which result in a single "point estimate," are used to characterize and prioritize environmental exposure risks to military members during a deployment (Smith, 1996). Deterministic techniques, using standard U.S. population default values in deployment exposure scenario evaluation to assess potential dose, have reducible levels of uncertainty. Using military specific

distribution functions will reduce uncertainty. Reducing uncertainty will provide a more informed risk assessment decision-making capacity. Therefore, an objective of the application of probability analyses in deployment exposure assessment is the focusing of resource-limited preventive medicine efforts through the identification and characterization of the distribution of risks to the military member.

1.2 Study Hypothesis

It was hypothesized that deterministic risk estimates calculated with EPA default values are greater than the upper 95% of the distribution of risk estimates calculated with military-specific input parameters in probabilistic simulation. Using the RME method, designed to calculate the upper bound risk estimate to protect the most susceptible, it could be assumed that the risk estimates would exceed the upper 95% level of the probability-derived risk estimate distribution.

It was further hypothesized that military-specific input parameters, and methodologies sensitive to the distributions of input parameters, will reduce potential sources of uncertainty in the risk estimates. Deterministic techniques, using default values, introduce reducible levels of uncertainty into the assessment of deployed military populations' risks. Uncertainty in risk estimates is the result of limited or inaccurate measurement of an exposure factor parameter (Bogen and Spear, 1987). The reducible levels of uncertainty are those associated with the input parameters that characterize the military population and the deployment environment. Characterization of deployment environments and the military population's attributes will decrease risk assessment uncertainty and enhance effectiveness of military public health. By applying statistical

methods to reduce uncertainty caused by parameter variations, improvement in risk assessments from deployment scenario evaluation is possible.

The aim of this research was to analyze military specific default parameters for input to the risk assessment model. Analysis of military specific default values for use in probabilistic simulation evaluating military deployment exposure risks will provide useful insights to the development and implementation of a comprehensive medical surveillance program. This research will suggest exposure assessment methodology to be used by military preventive medicine to address the following deployment risk questions:

1. Have deployed subgroups experienced high exposure or potential adverse effect inducing dose?
2. What is the range of risk for a particular subgroup of the deployed population?
3. What portion of the population exceeded the inhalation reference dose (RfD_i)?
4. How do the various deployed military population subgroups fall within the distribution of exposure and potential dose from inhalation route?

CHAPTER 2 BACKGROUND

2.1 Deployment Environmental Health Risks

Deployment environmental exposures and potential acute and delayed health risks to U.S. military personnel are a prominent interest and concern. The U.S. military now operates differently than it has during the past 30 years (Department of the Arny, 1993). One result of U.S. post cold war global commitment approach to national security strategy and policy is an increased participation in a variety of missions (DoD, 1996). A much

smaller force and an increased range of military operations -- include peacekeeping, peacemaking, humanitarian assistance, and disaster-response -- also will result in a population with unique and more frequent exposures.

The exposure risks are manifest in the rapidly changing environmental conditions around the world (Meybeck, Chapmand, 1993; United Nations, 1989,1992). Uncontrolled or poorly regulated industrialization and urbanization are a problem in many deployment locations (Jancar-Webster,1993; Ostrosky-Wegman, Gonsebatt, 1996). The misuse or inappropriate and often illegal handling and disposal of hazardous substances throughout the world has resulted in unidentified hazardous waste disposal sites containing industrial and energy production raw materials, intermediate products, final products, and by-products (Rummel-Bulska and Basavaraj-Schroth, 1994; LeClair, 1993). Conflict and natural disasters obviously can exacerbate environmental conditions (Glickman, Golding, Silverman, 1992).

Manipulation of the environment is a part of military warfare. Environmental warfare has been defined as the purposeful targeting of natural and man-made environmentally sensitive objects to achieve a specific military objective (Centner, 1996). Toxic materials may be intentionally released into the environment for area denial or to cause direct adverse health effects. Exposure to hazardous material during deployment may occur as the result of a deliberate attack on a bulk storage facility, or on industrial or energy production facilities. The destruction of industrial facilities, power production plants, and stored hazardous materials sites would have a major impact on the health for deployed forces.

Health concerns during deployment from exposure to air pollutants include the

spectrum of possible acute and chronic health effects. Once air pollution is generated, avoiding exposure is difficult, and many deployed personnel can be affected. Even relatively low levels of contamination can result in potentially harmful effects in a highly active population through inhalation of appreciable doses of contaminant. In areas of potential deployment, the air pollution levels may frequently reach and exceed the EPA and World Health Organization (WHO) acceptable limits for exposure. The WHO Global Environmental Monitoring System (GEMS) program, which monitors air and water quality world wide, has assessed and reported an increase in the frequency of detection of a wide variety of toxic and carcinogenic chemicals (WHO, 1992).

The new deployment demands and changing environmental risks call for a stronger public health role to prevent disease and non-battle injury (DNBI) while deployed. The increased frequency of deployments, changing environmental conditions throughout the world, and health problems of recent military deployments have resulted in demands for DoD to implement an environmental risk assessment program. Deployment environmental risk assessment by military public health is an important but undeveloped component of DoD's preventive medicine program.

Conventional chemical warfare remains an extremely dangerous threat to deployed military members (Wiener, 1991). It is a threat with a well-developed assessment history, and supporting military doctrine and preventive medicine recommendations, guidelines, and treatment regimens. As demonstrated by the preventive medicine's response to warfare chemical use during World War I, the U.S Military's history in occupational and environmental health demonstrates an ability set goal and objectives to achieve success (Bayne-Jones, Anderson, 1968). However, in the context of the larger potential

deployment chemical threats (Table 1), military preventive medicine is not fully prepared.

The assessment of deployment environmental contamination risks presents new challenges to preventive medicine personnel whose traditional field deployment assessments focused on field hygiene and sanitation, water quality assessment, vector control, and prevention of heat and cold exposure. Preventive medicine measures will increasingly be used to assess environmental pollution health risk, communicate these risks to the decision-maker, implement appropriate surveillance, and accurately assess potential adverse acute and delayed health outcomes. For DoD, both Vietnam and Desert Shield/Storm demonstrated the importance of a comprehensive environmental health risk assessment capability (IOM, 1994; NIH, 1994).

CHEMICALS	NUMBER
Grand Total	5,000,000
In Commerce	80,000
Industrial	72,000
New Industrial Chemicals	1,000/yr
Pesticides	600
Chemical Warfare Agents	8
Adapted from Final NTP Workshop Report, March, 18 1996, p 55	

Table 1: Extent of Chemical Hazards

2.2 Risk Assessment

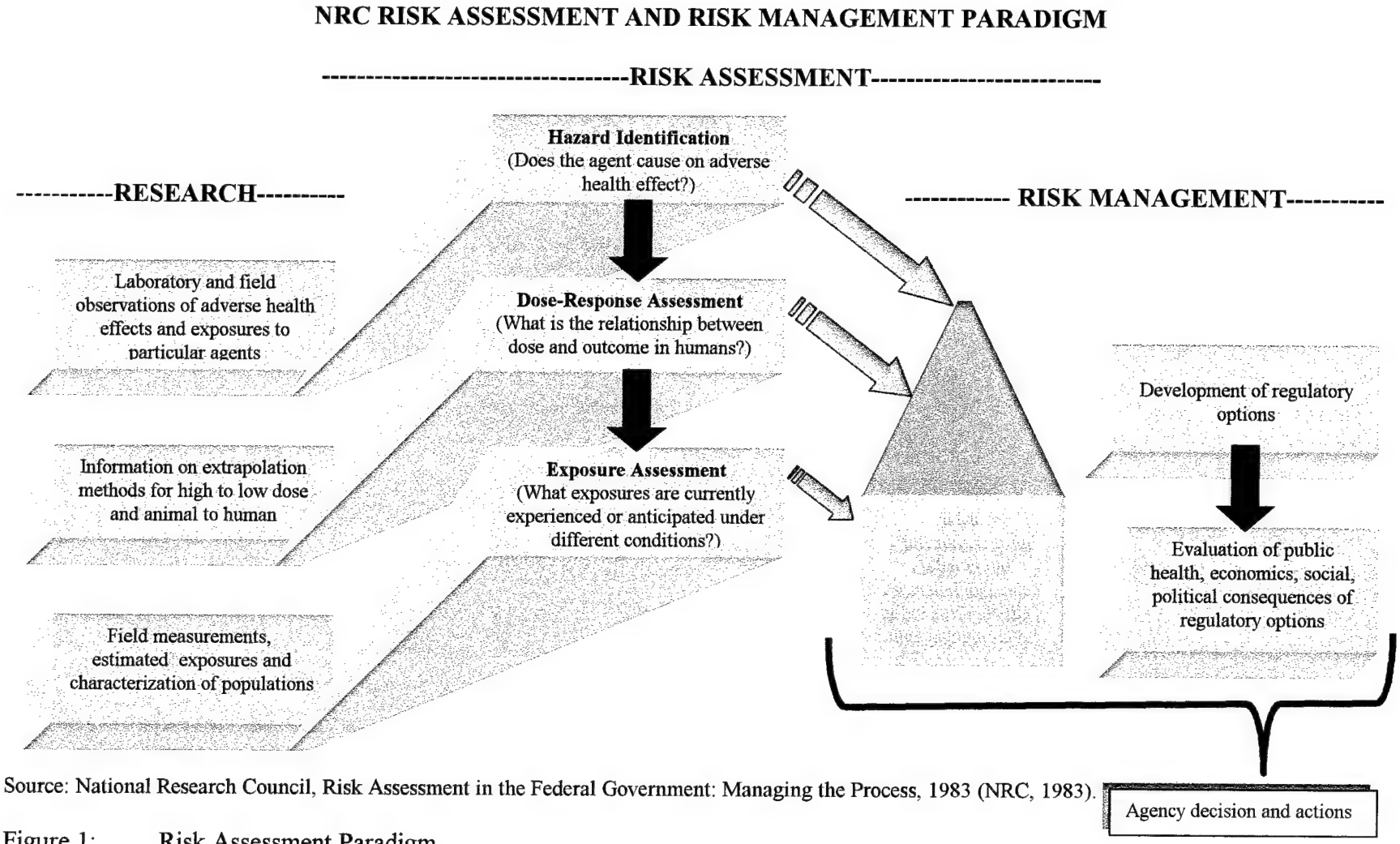
Since the 1970s, increasing numbers of regulations are addressing the growing evidence suggesting exposure to toxic chemicals in the environment causes adverse impacts on human health. The promulgation of these regulations preceded any consistent assessment processes. In an attempt to apply a systematic approach to assess adverse health effects and environmental damage from the uncontrolled release of hazardous substances, The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) became law in December 1980 (Federal Register, 1980). Despite this law, known as Superfund, the initial assessment and cleanup of hazardous sites were slow. By 1985, Congress demanded more action, and passed the Superfund Amendments and Reauthorization Act (SARA) to put more resources to work (Federal Register, 1986). An important result of these legislative mandates was the initial development of standardized approaches to assess risks -- specifically, the risk assessment process and the component inputs into the process.

SARA resulted in the development of EPA's Risk Assessment Guidelines (RAGS) Volume I, Human Health Evaluation Manual (EPA, 1989). RAGS provide standard guidance to risk assessors to ensure consistency and clarity of results. RAGS provided default exposure factors used to assess human exposure to site contaminants present in environmental media (e.g., water, soil, and air) and in the food chain. EPA's 1989 Environmental Factors Handbook (EFH) and the recently revised EFH, provide specific guidance and recommendations on exposure input factors for risk (EPA, 1988, 1997a). The EFH provides receptor parameter values for assessing human health risk. Parameters include physical factors (e.g., body weight, skin surface area), activity patterns (e.g., time

of residence, time spent outdoors, etc.), and intake factors (e.g., rates of inhalation and ingestion of drinking water). Lacking site-specific data available for a risk assessment data from, these exposure factors provided a consistent basis for calculating human health risk across a variety of exposure scenarios. EPA uses default values that represent averages, ranges, or point estimates derived from distribution data.

In 1983, the U.S. National Research Council established a paradigm for regulatory risk assessment situations (NRC, 1983). Risk assessment is the systematic characterization of potential adverse health effects resulting from human exposure to hazardous agents or situations (NRC, 1983). Environmental risk assessment relies on a variety of disciplines, such as public health, environmental chemistry, toxicology, occupational health, and epidemiology. The product is a qualitative and quantitative characterization that incorporates the assessment of a given exposure and a summary of the relevant potential health effects based on hazard identification and dose-response information. The components of risk assessment consist of hazard identification, dose-response assessment, exposure assessment, and risk characterization. The NRC risk assessment paradigm for characterizing risks consists of the traditional risk assessment components of hazard identification, dose-response assessment, exposure assessment, and risk characterization (figure 1).

Hazard identification consists of determining if a chemical is likely to cause an adverse health outcome when humans are exposed (NRC, 1983). This step consists of collecting and evaluating all data necessary to determine if the chemical is likely to cause adverse health outcomes. If a chemical is suspected to cause an adverse health outcome, a dose-response evaluation is then conducted.



Source: National Research Council, Risk Assessment in the Federal Government: Managing the Process, 1983 (NRC, 1983).

Figure 1: Risk Assessment Paradigm

Dose-response is the component of risk assessment that attempts to determine the effect of the range of dose on toxicity. Using experimental models, toxicologists generally attempt to extrapolate from observed high dose responses to hypothetical low-dose response in humans. Dose response is usually broken down into cancer and noncancer evaluations.

The next component of risk assessment is *exposure assessment*. Environmental exposures result from contact with pollutants in the air, water, and soil, and occur by inhalation, ingestion, or dermal pathways. Individual exposures may be modified by a) activity patterns, which determine encounters with various sources of exposures; b) bioavailability of the agent in time and place; and c) the frequency at which exposure occurs. For any given exposure, a person's resultant dose will depend on characteristics such as age, sex, and metabolism. It will also reflect susceptibility at the time of exposure and effects of concurrent exposures.

Risk Characterization is the accumulation and analysis of information collected in the steps identified above (NRC, 1983). Health assessors, decision-makers, and others apply the risk characterization to take appropriate action. It is the overall conclusion of the risk assessment process.

While uncertainty enters each of the steps, when appropriately applied, the NRC risk assessment paradigm could be extremely valuable in assessing environmental hazards and the health risks before, during, and after deployments. The potential for advances in deployment capabilities in terms of environmental health risk assessments are promising, considering advances in exposure assessment, toxicology, molecular epidemiology, biomarkers, biotechnology, remote and personal sensors, pharmacokinetic modeling, and

geographic information systems. A systematic but flexible framework for organizing and analyzing information from these diverse disciplines is essential.

Applying risk assessment to organize and analyze information in order to answer questions on the nature and extent of environmental risks to military deployments is a considerable task. Military deployments present challenges unlike those of other situations where risk assessment is applied. The main challenge is to effectively assess and communicate the environmental risks in the context of all other risks to mission accomplishment. Specifically, preventive medicine must a) identify and define environmental hazards presenting health risks, b) analyze and communicate levels of risk associated with exposure, and c) initiate and accomplish medical surveillance appropriate for the particular exposure.

2.2.1 Deterministic Risk Assessment Techniques

The EPA framework of risk assessment is structured to ensure a protective, but not necessarily the "best," estimate of the risk (EPA, 1992). To ensure a level of protection, the primary quantitative risk assessment approach required by EPA is the deterministic method. This method uses "upper-bound" assumptions as input variables in calculations that produce a single preset value, above or below which risk is present. "Upper-bound" assumptions are commonly the 90^{th} or 95^{th} percentile values of an input variable distribution. This method is referred to as "reasonable maximum exposure" and is described in EPA's RAGS (EPA, 1989).

Risk–based screening is essentially an RME "run in reverse." Another deterministic approach to risk assessment is risk-based screening. Risk-based concentrations (RBC) are

predetermined concentrations, published by the EPA, that use "upper-bound" values for hazardous site risk characterizations (EPA, 1993). The calculated onsite values for contaminants are compared to the calculated RBCs for risk prioritization. Contaminant levels that exceed the RBC are selected for further evaluation. To assess exposure risks during military deployments, DoD is currently using the RBC method. Reasonable maximum exposure and the risk-based concentration are discussed further below.

2.2.1.1 Reasonable Maximum Exposure

In accordance with EPA III and VIII guidelines, a reasonable maximum exposure risk which exceeds either 10^{-6} cancer risk or a non-carcinogenic hazard index of 1.0 will be calculated for the chemical(s) of concern (EPA, 1994). The receptor parameters for calculating RME estimates are available in the Exposure Factors Handbook (EPA, 1988). The RME formula combines upper bound and mid-range parameters to express an exposure that is both protective and not the worst possible case. Where distributions of values are available, those in the range of the 90^{th} to 95^{th} percentile are used in the RME formula.

EPA provides guidance on the use of environmental sampling data in the risk assessment calculation. The EPA recommends that the maximum detected site concentration be used where there is insufficient data to calculate a 95 % upper confidence level (UCL). The single-point exposure concentration therefore is either the upper 95 % UCL or the maximum detected concentration (EPA, 1994).

Potential human health hazards associated with exposure to noncarcinogenic substances are evaluated separately from carcinogenic risks. For chemicals such as volatile

organic compounds, which cause harmful effects other than cancer, the EPA measures the risk in a hazard quotient (HQ). The noncarcinogenic risks from exposure to chemical are based on consideration of a threshold for injury. If an exposure remains below a certain threshold, no harmful effects are assumed. The daily intake of a chemical over a specified period of time (e.g. lifetime or some shorter time) from one exposure route is compared with a reference dose for a similar period to determine a ratio called the HQ. The simplified formula used to calculate the HQ is shown in figure 2.

More specifically, using site data and population input parameters, the potential for noncarcinogenic effect is calculated as a HQ by dividing the chemical-specific average daily dose (intake) by the chemical specific pathway-specific reference dose (RfD). The calculation is outlined in the inhalation HQ formula in figure 3. An HQ less than 1.0 indicates low adverse health risk, while an HQ of 1.0 or greater indicates a greater level of concern for potential noncancer health effects (EPA, 1994).

Hazard Quotient = Intake/Reference Dose (RfD)

Figure 2: Simplified Hazard Quotient Formula

$$HQ = \frac{C * IR_w * EF * ED}{BW * AT} \div RfD_i$$

HQ	=	Noncarcinogenic hazard quotient (unitless: ratio of estimated dose to reference dose)
RfD_I	=	Reference dose inhaled
BW_a	=	Body weight adult (kg)
AT_n	=	Averaging time, noncarcinogen (d)
Ef_r	=	Exposure Frequency (d/y)
Ed_{tot}	=	Exposure duration total (y)
IRA_a	=	Inhalation, adult (m^3/d)
C_a	=	Contaminant concentration in air $\mu g/m^3$

Figure 3: Hazard Quotient Formula

To assess the overall potential for noncarcinogenic effects posed by more than one chemical a Hazard Index (HI) is calculated. The HI is equal to the sum of the HQs for individual chemicals (figure 4). The HI is generally applied only appropriate for those chemicals that produce similar adverse effects. When the HI exceeds 1.0, there may be concern for health effects. If a HI is lower than 1.0, it is unlikely that any adverse health effects will occur; therefore it is generally considered an acceptable level of exposure (EPA, 1994).

$$\text{Hazard Index} = HQ_1 + HQ_2 + HQ_3 + \ldots$$

Figure 4: Hazard Index Formula

2.2.1.2 Risk Based Concentrations

DoD uses a risk-based screening approach for identifying contaminants of concern and for assessing health risks in a deployment environment. Risk-based concentration applies predetermined risk levels in calculating a point estimate of risk from the concentration of chemicals in the environment (Figure 5). An essential value of risk-based screening is the quick capability for an initial screening of potential contaminants of concern (EPA, 1993). Risk-based concentrations are used for rapid screening of new data, selecting contaminants for formal risk assessment, and prioritizing cleanup of hazardous waste sites (EPA, 1993).

EPA's sets of "protective" default values in the RBCs provide a fixed level of risk for over 600 chemical concentrations in the air, water, soil, and fish (EPA, 1993). The contaminant levels of this list represent a lifetime 10^{-6} risk of cancer, or systemic HQ or HI of 1.0. Risk-based concentration screening involves identifying the maximum concentration of contaminants and determining if the maximum concentration exceeds the calculated risk based-concentration for that medium. If the level is exceeded, a more extensive and detailed risk assessment may be completed; if the contaminant does not exceed the RBC level, the contaminant is dropped from the risk assessment.

As a "risk assessment run in reverse," the RBC approach has some applicability to a military deployment. While many chemicals may be sampled and detected, a few contaminants and routes of exposure dominate baseline risk assessments. It is not necessary or, in many situations, possible to collect information on all possible contaminants. Many, if not most, are inconsequential to the accomplishment of the mission or the health of the deployed member. Identifying these dominating chemical risks as early

as possible in a deployment could have significant benefits to the deployment risk assessment process. In such cases, where preliminary sources and likelihood of contaminants are not available, the use of a RBC may be useful in the early, baseline assessment of a deployment location.

RBC (Ambient Air)

$$= \frac{\mu g}{mg^3} \qquad \frac{THQ \cdot RfD_i \cdot BW_a \cdot AT_n \cdot 1000\ \mu g/mg}{Ef_r \cdot Ed_{tot} \cdot IRA_a}$$

THQ	=	Target Hazard quotient = 1
RfD_I	=	Reference dose inhaled
BW_a	=	Body weight adult (kg)
AT_n	=	Averaging time, noncarcinogen (d)
Ef_r	=	Exposure Frequency (d/y)
Ed_{tot}	=	Exposure duration total (y)
IRA_a	=	Inhalation, adult (m^3/d)

Figure 5: Risk Based Concentration formula

While both the RME and RBC approach to risk assessment most likely insure the population is protected against the likelihood of adverse health effects from exposure to environmental contaminants, the deterministic approach has important limitations in deployment applications. Primarily, application of a single-point deterministic value fails to provide information about the distribution of both the input variables and the risk estimates. Secondly, the default values are based on the general U.S. population, which has different characteristics than the active duty military force. Finally, the level of extent of "conservative" assumptions may present an unrealistic level of risk, although this has not been fully tested.

2.2.2 Probabilistic Risk Assessment

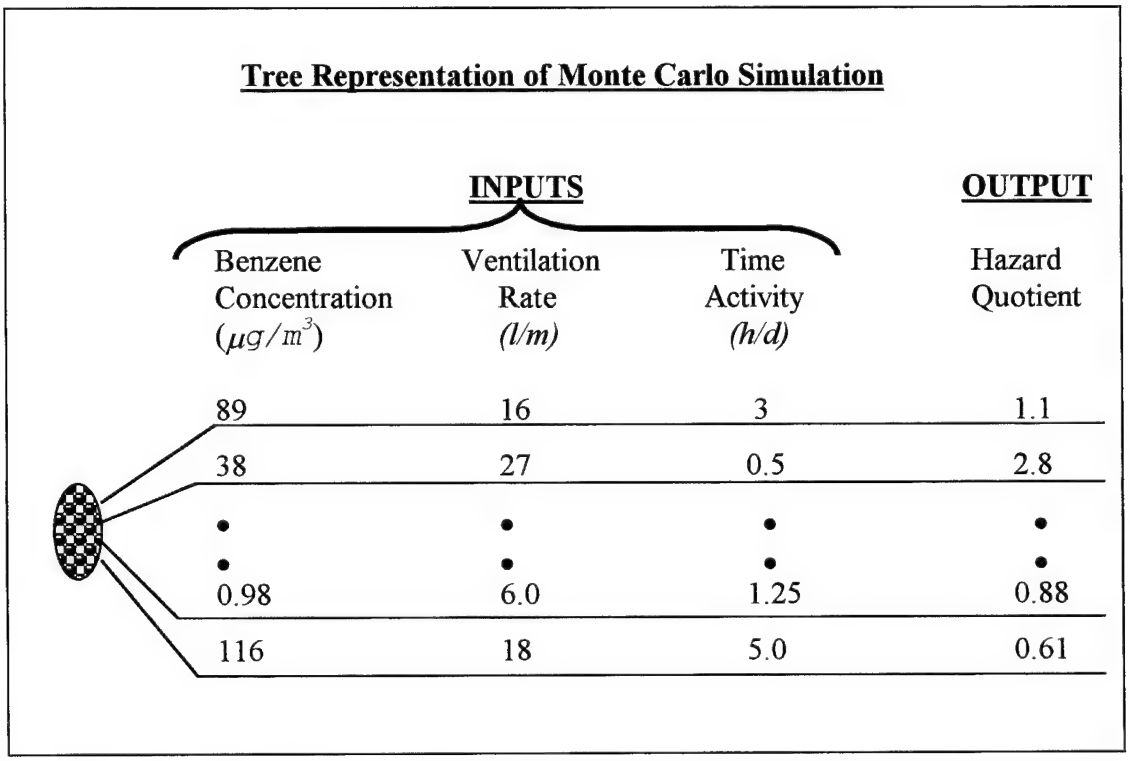
A criticism of deterministic techniques is that a characterization of the range of potential risks is not provided in a single point estimate. The level of conservatism by the risk assessor is not portrayed in a singular point estimate. Consequently, a current direction of risk assessment is an increase in the extent of characterization of the risk. This direction includes as a component of the risk characterization, the range of exposure, and risk estimates derived from the risk assessment (Finley, Paustenbach, 1994). In an attempt to address the criticism of the deterministic technique, EPA supports the careful use of probabilistic risk assessment in certain circumstances (EPA, 1997).

Probability assessments provide a range of risks, as opposed to a point estimate, incorporating distributions of exposure characteristics in a human population into the risk estimates. The method randomly chooses one possible value from the determined distribution for each variable in the risk assessment calculation. The risk assessment

variables are initially described as a particular probability distribution that characterize the range and variability of the set of possible values. These probability distribution functions (PDFs) characterize the uncertainty associated with that particular input variable. The PDF is an expression, for continuous variables, of the probability that the random variable falls within some interval (Mooney, 1997). The selection of random values from each input distribution is repeated until the process creates a representation of the resulting distribution. The result of probabilistic risk assessment is characterization of risk unavailable in the single-point estimates: a range of risks as opposed to single-point estimates.

Monte Carlo simulation is a conventional technique used in probability risk assessment (Mooney, 1997). Monte Carlo simulations involve the process of approximating an output of a model through the repeated random application of the model's algorithm. The Monte Carlo process creates a statistical population based on parameters of a real population. By repeatedly drawing random samples from these artificial populations, the output should resemble aspects of the real world population.

Each iteration of the output point in the distribution consists of a sample taken from each of the input distributions. For example, one sample is taken from the lognormal distribution on benzene concentration and one sample from the normal distribution on ventilator rates. This process is repeated with each input distribution until a satisfactory intake distribution is obtained (e.g., 10,000). A tree representation of a Monte Carlo analysis for this proposal is presented in figure 6.



Adapted from Gallent (Gallent, 1977).

Figure 6: Tree Representation of Monte Carlo Simulation

A significant challenge in the application of probabilistic models is establishment of probability distributions for the exposure factors (Burmaster, Anderson, 1994; Taylor, 1993). Recommended input distributions were used when information was available and applicable to the military population and deployment scenario. In other cases, available information was used to construct distributions using military specific data. For others, where information was not available, professional judgement was used to construct distributions.

The goal of applying a Monte Carlo analysis to inhalation exposure in the deployment sites is to characterize the uncertainty in estimates of this type of exposure risk. The process will approximate input distribution with a set of discrete points. This set of discrete points represents the input parameter distribution. In this study, input variables (including time-activity, inhalation rates, time in theatre, work/rest cycles, and benzene concentrations) will become random variables with their estimated PDF. The PDFs for this study are derived from the site-specify benzene concentrations, and available and other relevant data sets.

For the DoD, exposure values relevant to the military population and application of probabilistic risk assessment may provide a better-characterized picture of risk to the deployed population. A more realistic assessment of health risk for military deployments is a vital component of effective preventive medicine initiatives. This study uses a Monte Carlo simulation using the risk assessment equation with Decisioneering's Crystal Ball®, version 4.0 for Windows (Decisioneering Corp., 1996).

2.3 Inhalation Exposure Assessment

Exposure assessment involves estimating the type and magnitude of chemical exposure to the potential receptor at a specific site. Inhalation exposure is the introduction of a contaminant at the environment-human interface, the uptake of contaminants by absorption through exposed tissues, and the transfer of the contaminant to a site of action (Federal Register, 1992). The health risks associated with human exposure to airborne toxics are a result of concentration of air pollutants, chemical species, exposure time, ventilatory rates, and host susceptibility, among other factors. All of these variables introduce uncertainty in the exposure assessment. Figure 7 outlines the concept of exposure, intake, and dose.

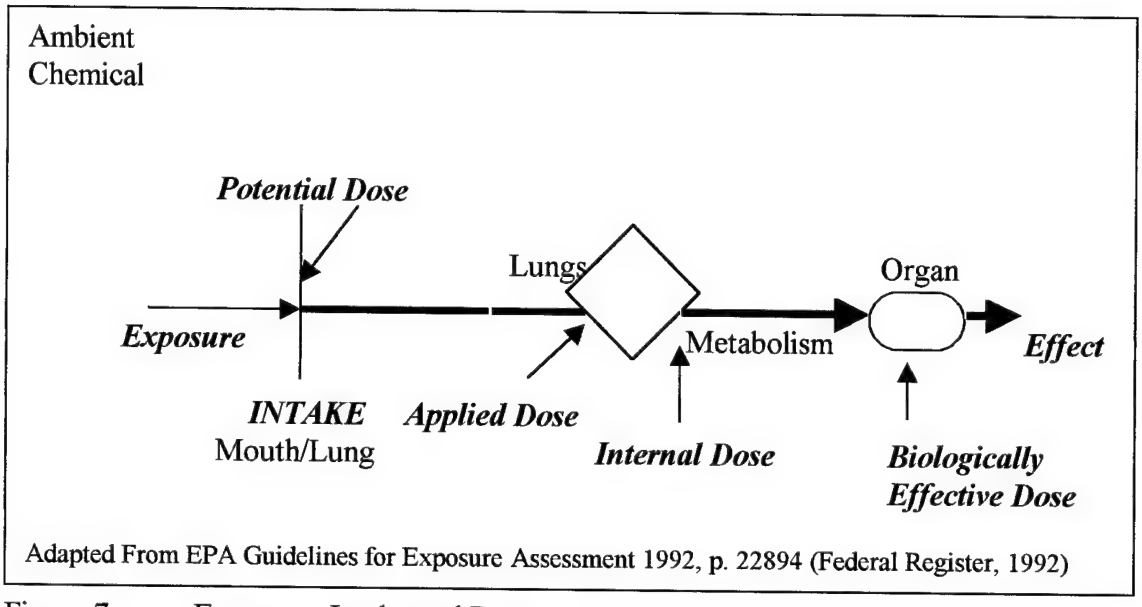


Figure 7: Exposure, Intake and Dose

Generally, human exposure is considered contact of an agent with an outer point of entry (Federal Register, 1992). Exposure involves a chemical concentration at a point of contact with the human boundary. Quantitatively, this can be calculated mathematically with a time-dependent variable, and expressed in concentration-time units. For airborne contaminants, exposure concentrations are expressed in units of $\mu g/m^3$, mg/m^3, ppm, or ppb. Figure 8 is a simplified form of the formula, where E is the estimate of the magnitude of exposure and C is the chemical concentration per unit of time (Δt).

$$E = C\Delta t$$

$$E_{chemical} = (\mu g/m^3 \times m^3/day) \times days = \mu g$$

Figure 8: Exposure Calculation

The calculation of potential dose from inhalation involves integrating exposure concentration with the intake rate of air and a normalization variable. The inhalation or intake rate of a chemical depends on the exposure concentration and the amount of chemical entering the lungs per input time -- typically expressed as m^3/hour or m^3/day. Estimating potential dose must then be expressed in terms that can be compared with relevant toxicologic dose-response relationships (Klaasen, 1996). Typically, this is expressed as an average dose over a period or time per body weight or body surface area. Dose rate is frequently normalized to the standard parameter, body weight. With these factors added, the equation for potential dose is shown in figure 9. Here, C is the concentration of the chemical, IR in the intake rate, ED is the exposure duration, BW is body weight, and AT is the averaging time or the time over which the dose is averaged. For airborne contaminants, potential dose is typically expressed in units of μg/kg or mg/kg.

$$\text{Potential Dose} = [C \cdot IR \cdot ED]/[BW \cdot AT]$$

$$D_{p\ \text{chemical}} = (\mu g/m^3 \times m^3/\text{day} \times \text{yrs})/(\text{kg} \times \text{day/yr}) = \mu g/\text{kg}$$

Figure 9: Potential Dose Calculation

Commonly in exposure assessment, information is not readily available, and simplifying assumptions are applied. Parameters associated with target site and target site interaction with the environment are commonly simplified and estimated. Examples of parameters include body weight, inhalation rate, excretion rate, and exposure duration. In most risk assessments the assumptions are characterized as "conservative" and provide for a significant margin of safety. According to the EPA, these input values are ". . .a rationally derived, conservative estimate . . ." which support a high-end portion of the exposure assessment (EPA, 1991). A high-end estimate, the RME estimate, is above the 90^{th} percentile of the population distribution.

The application of simplifying assumptions in a deployment risk assessment has not been investigated. This study investigates the use of default values in assessing noncarcinogenic health risk from exposure to benzene during deployment. Both noncarcinogenic and carcinogenic health risks require appropriate characterization of the population and environment during military deployments. Therefore, the tools and methods proposed by this study are applicable in characterizing both risks.

Assessing potential noncarcinogenic health risk from inhalation exposure to benzene, and other chemicals, is done through a HQ described previously. This ratio between the estimated dose and the reference dose over a specific period is calculated by dividing the chemical-specific average daily dose by the chemical-specific reference dose. Input variables include contaminant concentration, inhalation rates, exposure frequencies, body weight, averaging time, and exposure duration.

Ventilation rates are critical in estimating potential dose of solvent via inhalation, and the effect of ventilatory rates on pulmonary uptake of solvents has been reported

(Zenz, Berg, 1970). For many chemicals uptake is proportional to the intake (ventilation). As physical activity increases, the removal of chemicals by the circulatory system from the lungs does not necessarily increase, but chemicals are more rapidly supplied to the alveoli by increasing the rate or depth of respiration (Zenz, Berg, 1970).

The role of inhalation rate on potential dose, inhalation rates for many kinds of activities have been investigated and applied to exposure assessments (Funk, Sedman, Beales, Fountain, 1998; Ulfvarson, 1983a; Ulfvarson, 1983b). Selected agency ventilatory rates by physical activity for use in exposure assessment and risk assessment are presented in table 2. It can be seen that both activity level ventilation rates and total daily ventilatory rates reported across agencies. The EPA's recommended ventilation rates used in risk assessment for an adult, before the 1997 update to the Environmental Factors Handbook, is $20m^3$/day for adults (EPA, 1988,1997). The inhalation rates cited in the revised EPA EFH is 15.4 m^3/d for adult males, with further recommendations that $1.3m^3$/hr average and 3.3 m^3/h upper percentile should be used for outside workers (EPA, 1997). Other agencies have determined different inhalation rates based on population specific characteristics and the source research.

Several variables affect estimating inhalation rates over time. These include age, gender, body weight, body surface area, and physical activity. Populations with different characteristics may have significantly different ventilatory rate distributions. These differences represent uncertainty in the risk estimate. For example, a population with inhalation rates higher than the default input values may have a higher potential dose and could be considered a "high-risk" group. Conversely, populations with lower inhalation rates than the default values may receive a lower potential dose.

Physical Activity	EPA (EPA, 1988) (m^3/h)	International Commission on Radiological Protection (Snyder, Cook, Nasset, Karhausen, Howell, Tipton, 1975). (m^3/h)	California Air Resource Board (CARB, 1993) (m^3/h)	Layton (Layton, 1993) (m^3/h)
Resting	0.7	0.45	0.54	0.4
Light	0.8	1.2	1.45	0.7
Moderate	2.5	-	1.93	1.7
Heavy	4.8	2.6	3.63	2.6
Daily	20 m^3/day	23 m^3/day	-	17 m^3/day

Table 2: Ventilatory Rates During Physical Activities

An approach to reduce uncertainty in inhalation exposure assessment is to assess distributions of time spent at various ventilatory levels. Based upon characterization of the type of activity, location of activity, and population characteristics, ranges of inhalation exposures in populations can be determined. By combining activity time with ventilatory rates, the distribution of inhalation rates can be estimated for deployment scenarios.

2.4 Military Member Risk factors

Adapting occupational or environmental protection default values and exposure standards for use in deployment risk assessment should be done with caution. U.S. population or occupational default values most likely do not apply in a deployed military population. Deployment environments and military population characteristics are different from both the U.S. occupational and the general population settings. Military deployments present unique conditions, which may affect potential dose level, performance, and health outcomes. Table 3 identifies some of the changes in deployment activity patterns and population characteristics. This table represents the author's experience and understanding of military deployments, a review of military deployment after-action reports, and personal interviews. Generally, military deployments are physical and psychologically demanding.

The nature of the deployment environment could result in a very different set of exposure characteristics. There are unique physical and psychological stresses associated with all military deployments. In a deployment setting, military personnel typically work and live in the same environment. Work hours can be greatly extended and significantly different from the occupational setting norm of 8 hours. A 12-hour workday, seven days a week is not an uncommon deployment work schedule. Emotional and psychological

stressors of deploying to new and hostile environments are considerable.

The recognized physical demand on active duty members in performing military tasks is the impetus for DoD to promote and maintain a relatively healthy workforce. Medical standards for entry into the military are rigorous. Once on active duty, all personnel must meet physical fitness and body fat standards, which are assessed routinely. Promotion, favorable actions, and even retention on active duty are based on passing prescribed physical performance and weight standards based on age, gender, and height. Additionally, the active duty force is relatively young. The U.S. DoD active duty strength is currently about 1.2 million with a mean age of 27.4 years (Iowa Persian Gulf Study Group, 1997).

Psychological demands of military operations are as extraordinary as the physical demands. The current U.S. military also has a highly technically trained force that increasingly performs highly complex tasks and operates state of the art technologies related to military activities. Military hardware and technology places greater demand on the human cognitive skills. Technological developments have increased the precision, lethality, and operating sophistication of weaponry, but also have resulted in demands on the human operators, such as increased decision making loads and compressed reaction times.

DEPLOYMENT POPULATION	DEPLOYMENT ALTERED ACTIVITY
Soldier Task Characteristics	+
Manual Dexterity	+
Physical Effort	+
Time Pressures	+
Decision Making Requirements	+
Environment	+
Ambient Chemical Exposures	+/-
Environmental Conditions	+/-
Living Condition	+
Work Regiment	+
Mental Concentration/Attention Demands	+
Visual	+
Auditory	+
Motor	+

Table 3: Alteration in Activities during a Military Deployment

CHAPTER 3 LITERATURE REVIEW

The literature review strategy for this research focused on exposure factors used in human health risk assessment, the target chemical, exposure limits and altered work schedules, and military population and deployment characteristics. Literature review included peer reviewed sources, and from within DoD relevant technical bulletins, training manuals, field manuals, and defense related policy and planning documents. The literature review included a variety of sources from within the DoD. Preliminary and follow-up literature search strategies were based on determining: 1) exposure parameters used in exposure assessment, 2) parameter similarities with active duty military populations, 3) military deployment work and living conditions affecting parameters, 4) methodologies available to assess deployment exposure risks, 5) current environmental and occupational exposure standards, and 6) deterministic and probabilistic techniques.

3.1 Benzene (C6H6): Target Substance

Benzene was selected as the target chemical for the evaluation of deployment inhalation exposure assessment. This selection was based on 1) frequency and concentration of ambient benzene at the deployment sites, 2) ambient levels in relation to U.S. ambient environmental levels, 3) sample concentrations exceeding the RBC value, 5) potential to result in non carcinogenic adverse health effect, and 4) comprehensive literature database. Also, benzene was one of the most frequently identified air contaminants in the former Yugoslavia; it was detected in 63 percent of the air samples. Benzene was one of the measured compounds that exceeded the risk-based concentration level. Toxicological and epidemiological evidence indicate benzene presents carcinogenic

and noncarcinogenic health risks at sufficient levels of exposure (ATSDR, 1996).

Benzene is a widely used industrial solvent produced in a variety of processes. Benzene is a member of the larger class of volatile organic compounds, which includes structural family groups of aromatic and chlorinated hydrocarbons, aliphatics, alcohols, ketones, ethers, aldehydes, nitroso compounds, and phenols (Clayton, Clayton, 1994). As a class of chemicals, solvents are ubiquitous throughout the world, an important raw material produced in large volume, and have great variety of uses. The more extensive uses of benzene include as a solvent, as a chemical intermediate in the manufacturing of many other chemicals, and as a gasoline additive. Benzene can be found in cleaning fluids, paints, sealant, aerosol sprays, and a variety of other common products (Kent, 1992).

Benzene and its capacity to produce adverse health effects have been extensively studied for several decades. As early as the1920s, there were attempts to remove benzene from the work place as an occupational exposure risk (Kent, 1992; Hamilton, 1931). The current Agency for Toxic Substances and Disease Registry, in its Toxicological Profile for Benzene, cites more than 800 reference articles on benzene exposure and adverse health effects (ATSDR, 1996).

Benzene was one of the selected target volatile organic chemicals in EPA's Total Exposure Assessment Methodology (TEAM) Study (Wallace, 1987). The purpose of the USEPA TEAM study was to assess methods in measuring human exposure to toxic substances in air and drinking water. Area monitoring and personnel dosimetries were evaluated in estimating the distribution of exposures for a targeted population.

Several findings of the TEAM study have direct relevance for exposure assessment during deployments. First, the TEAM study found mean personal air measurements of

target chemicals greater than the mean outdoor concentrations of the chemicals (Wallace, 1987). The authors suggest that personal activities (occupation, pumping gas, etc.) and consumer products (cigarette smoking) are a primary reasons for the difference (Wallace, 1987). Additionally, for the chemicals measured, greater than 99 % of individual exposures occurred through air (Wallace, 1987). The implications of the TEAM study methods in a deployment exposure surveillance program are discussed in the Assumptions and New Direction Sections.

The primary routes of exposure to benzene are inhalation and dermal contact. The inhalation route is the most important in terms of acute and chronic health effects from exposure to benzene for the general population. Ingestion may be a route of exposure in certain occupations and for certain activities of the general population (ATSDR, 1996). The most common outdoor source of exposure for the general population is from automobile related activities (ATSDR, 1996). In the U.S., ambient environmental concentrations are typically in the ppb (part per billion) range, with indoor levels and cigarette smoke being the most significant source of benzene exposure (Wallace, 1987; (ATSDR, 1996). Table 4 is a list of benzene concentration reference points.

BENZENE	
Mean Concentration of Deployment Sites	$5.22\mu g/m^3$
Maximum Concentrations at Deployment Sites	$106.19\mu g/m^3$
EPA Region III RBC (EPA,1998)	$0.22\ \mu g/m^3$ Lifetime cancer risk 10^{-6}
RfC (EPA, 1998)	6.0×10^{-2} mg/m^3 *
RfD_i (chronic) (EPA,1998)	$1.71\mu g/kg/d$
RfD_I (subchronic) (EPA, 1998)	17.1 μg/kg/d
ACGIH TWA (ATSDR,1996)	32.0×10^3 μg /m^3/8-hour
OSHA PEL (ATSDR,1996)	$32.0 \times 10^2 \mu g$/8-hour
Median Environment Levels (urban/rural) (ATSDR,1996)	5.86/1.5μg /m^3
Odor Threshold (ATSDR,1996)	4,890 –15,322μg /m^3

Table 4: Benzene Reference Levels

* RfC and RfD for benzene are currently under review by the EPA. The RBC level for benzene RfD_i is an EPA-NCEA Regional Support provisional value of 1.71×10^{-3} μg/kg/d. The subchronic RfD_I was calculated from a RfC of 6.0×10^{-2} obtained form a Provisional Risk Assessment Issue Paper for the Subchronic RfC for benzene (EPA, 1998).

Adverse health effects of benzene range from death from acute exposure to high concentration, to a variety of effects at chronic low level exposures. Elevated exposures can affect the nervous system, while long-term exposures at low levels have been suggested to impair blood cell formation and bone marrow function, damage the central nervous system, and cause some types of cancers (ATSDR, 1996). Ocular, gastrointestinal, renal, respiratory, cardiovascular, immunological and lymphatic, neurological, reproductive, and carcinogenic effects have been demonstrated in animal toxicologic studies or clinical epidemiological evidence in humans following inhalation of benzene. Short-term health effects from exposure to moderate benzene levels include drowsiness, dizziness, headache, eye, skin, and respiratory tract irritation (ATSDR, 1996). Drew and Foust calculated the LC_{50} at 13,700 ppm (parts per billion) for a 4-hour exposure in rats (Drew, Fouts,1974).

Both the International Agency for Research on Cancer and The National Toxicological Program classify benzene as a carcinogen in both experimental animals and in humans (IARC, 1982; NTP, 1986). Case reports and epidemiological evidence describes an association of benzene with leukemia and occupational exposures to benzene and benzene-containing mixtures (ATSDR, 1996; IARC, 1982; NTP, 1986).
An EPA-NCEA (National Center for Assessments) review of published literature since 1985 on the carcinogenicity of benzene concludes that exposure causes acute nonlymphocytic leukemia and other blood-related disorders in humans (EPA, 1998).

The hematopoietic system is a major target for benzene. Exposure to benzene and resultant metabolites appears to affect normal hematopoesis. Exposure to benzene for several months to years results in a reduction in the three major types of red blood cells --

panctyopenia (ATSDR, 1996). Effects on lymphocytes in humans have been demonstrated in several occupationally exposed populations. (Aksoy, 1989; Aksoy, Dincol, Akgun, 1971; Kipen, Cody, Goldstein, 1988; Rothman, Smith, Hates, 1996; Rothman, Li, Dosemeci, 1984) LOAEL (lowest observable adverse effect level) and NOAEL (no observable adverse effect level) values of benzene hematotoxicity are based on animal studies that show benzene produces a wide range of toxic effect at all levels of the hematologic system (ATSDR, 1996).

The current provisional subchronic RfC of 6 $x10^{-2}mg/m^3$ is derived from Baarson, Snyder, and Albert as the principal study (Baarson, Snyder, Albert, 1984). The protocol of Baarson et al. included male mice exposed for 6 hours/day, 5 days/week for 178 days. A significant ($p>0.05$) decrease in levels of red blood cells at 66 and 178 days, and lymphocytes at all three sampling times in the peripheral blood of benzene exposed mice is reported. A LOAEL of $32mg/m^3$ is based on depressed hematopoieses with an uncertainty factor adjusted for exposure time and inclusion of an uncertainty factor of 100 results in the provisional subchronic RfC of $6x10^{-2}mg/m^3$.

While reliable effect and susceptibility biomarkers are not available for benzene, biomarkers of exposure are available. For example, urinary sulfate ratio as a non-selective test may indicate exposure to benzene above background by comparing the ratio of inorganic to organic sulfates in urine (Hammond, Herman, 1960). Urinary phenol measurements are used in occupational monitoring (OSHA, 1987; Astier, 1992). Levels of benzene excreted in expired air and breath are increasingly being used as a measure of exposure (Hunter, 1968; Brugnone, Perbellini, Faccini, 1989; Wester, Maibach, Gruenke, 1968).

3.2 Modified Exposure Limits

Because the military is a healthy workforce, an occupational standard of exposure level may be more appropriate. Threshold Limit values (TLVs) have been in place in the U.S. occupational setting for over 40 years, resulting in the significant protection from adverse health effect among workers, and may be a more appropriate exposure standard than the EPA for deployments (Stokinger,1981). According to the ACGIH, TLVs are limits of airborne concentrations of substances that healthy workers that may be exposed to day after day without adverse health effects (Documentation of the Threshold Limit Values, 1992). The ACGIH-TLVs are therefore theoretically less conservative than the EPA standard because the EPA must account for protection of the aged, young, infirm, and the fact that an individual may be exposed continuous for 70 years (Paustenbach, 1994).

However, military deployments result in unusual work schedules, in addition to an environment where members both live and work. Without consideration of this extended exposure period, adopting an occupational exposure standard designed to protect workers in an 8 hour a day, 5 day a week, 40-hour work week may be inappropriate for a military deployment. Background literature search focused on methods to address altered work schedules and exposure times.

The need to adjust occupational exposure standards for work schedules different from the 8 hour a day, 5 day week work implemented in many industries for many years is well recognized. (Paustenbach, 1994; Brief, Scala, 1975; Nollen, 1982; Nollen; Martin, 1978; Hickey, Reist, 1977). There are two general categories of models for adjusting exposure limits for unusual work schedules. These are the simple mathematical formulas

for the adjusting exposure limits, and the pharmacokinetic models that account for biological half-life and the chemicals' pharmacokinetic characteristic.

Varying mathematical models for adjusting exposure levels for altered work schedules have been suggested since the early 1970s (Paustenbach, 1994; Mason, Dershin, 1976; Hickey, Reist, 1977; Hickey, Reist, 1979), and guidelines for using these models to adjusting exposure limits have been directed by OSHA (OSHA, 1989, 1990). In general, the mathematical models are based on the total number of hours worked per day, and the total number of hours between exposures. While these formulas are simple to use, biological half-lives of the different chemicals are not included; therefore, the amount that the limit should be lowered is overestimated, providing a larger degree of reduction than the pharmacokinetic models (Paustenbach, 1994).

Pharmacokinetic models for adjusting exposure standards have been proposed by Mason and Derision, Hickey, Roach, and Anderson (Mason, Dershin, 1976; Hickey, 1980; Hickey, 1983; Roach, 1978; Anderson, MacNaughton, Clewell, Paustenbach, 1987). Pharmacokinetic models take into account the biological half-life of the agent, and generate an exposure reduction factor that includes the metabolic processes of absorption, distribution, biotransformation, and elimination of toxicants. The models take into account body burden of the toxicant as well as the exposure duration, and produce a less conservative reduction factor.

3.3 Exposure Parameters

A comprehensive risk assessment evaluates the hypothetical risk from exposure through the four different media: soil, sediment, water, and air (EPA, 1988). Exposure pathways evaluated usually include ingestion of soil, inhalation of volitiles

and/or suspended contaminants, ingestion of food or drinking water, and dermal contact. Population specific parameters considered in evaluating specific exposure pathways include physical factors, activity patterns, frequency and duration of exposures, and intake factors (EPA, 1988). Many of the exposure factors included in the EPA EFH were derived from many different studies. With the exception of the U.S. Army drinking water ingestion rates included in the 1997 EFH guidelines, data specific to military populations included in the EPA EFH were not identified. If considering non-deployment living and working conditions such as those in garrison, the EPA exposure guideline may be adequate for protecting the health of the military member. Except for the military training and induction facilities, garrison military life may reflect that of the general civilian community.

The premise of this research is that in deployment situations, many exposure parameters change or are altered, and deployment specific risk assessment input parameters should be used in the risk model. Exposure and population characterization specific to military deployment for application in exposure assessments have not been identified or evaluated. Therefore, the literature search emphasis was on identifying those deployment-input parameters that may be different from garrison environment and/or different from the EPA EFH recommended values.

The background literature search focused on general population input parameters. Several approaches in developing exposure groups have been explored by a number of investigators (Chekoway, Rice, 1992; Dement, Harris, Symon, Shy, 1983; Dodgson, Cherrie, Groat, 1987; Kromhout, Heederik, 1995; Rappaport, 1991; Rice, Harris, Lumsden, Symons, 1984; Seixas, Moulton, Robin, Rice, Attfield, Zeller, 1991; Stewart, Herrick, 1991; Stewart, Lees, Francis, 1996) (See table 5). Information obtained was

used to guide further literature searches and evaluation of data sets of input parameters for use in developing exposure group classifications for deployment exposure environmental risk assessments. In general, the most heavily relied on literature for this research started with EPA Exposure Factors Handbook. Source documents for the parameters recommended in the EPA EFH were then obtained and reviewed.

This research relied on exercise physiology and environmental medicine research conducted at the U.S. Army Research Institute of Environmental Medicine (USARIEM). The USARIEM conducts research on exposures to environmental extremes as it may effect the health of soldiers and the military mission. The research by this organization is published in peer reviewed journals, and in technical reports, field manuals, and training bulletins for use by DoD.

Investigator	Exposure class definition
Rice, Harris, Lumsden, Symons (1984)	Task – product
Kromhout, Heederik (1995)	Job – location
Seixas, Moulton, Robin, Rice, Attfield, Zeller (1991)	Occupational group-mine-year, Mine-year, Year
Dement, Harris, Symon, Shy (1983)	Uniform task – exposure zones
Dodgson, Cherrie, Groat (1987)	Facility – year
Adapted from Stewart et al *Scand J Work Environ Health* 1996;22:405-14, p407	

Table 5: Exposure Class Definitions

No daily ventilatory rate estimates specifically for military members were identified in the literature review. One study was identified which assessed ventilatory rates of soldiers performing military specific tasks. In a crossover-designed study, the USARIEM, Occupational Physiology Division, evaluated the metabolic costs of military members performing 42 military-specific tasks (Patton, Murphy, Bidwell, Mello, Sharp, 1995). The study measured Ve, and other physiological parameters on male and female soldiers performing each of 42 military specific tasks. The physical intensity level ranged from 10% to about 75% of maximal oxygen uptake while wearing the military battle dress uniform.

Military activities are physically demanding, and in general, soldiers are young and physically conditioned. Physiological demands of combat ready soldiers performing specific tasks can be compared to trained athletes in competition. Patton et al. recorded a mean Ve_{max} (maximum expired-minute ventilation) of 137.2 liter/min, with a maximum of 174.4 liters/min on soldiers performing physically demanding military tasks (Patton, Murphy, Bidwell et al., 1995). Appendix A is a table of physiological parameters measured on soldiers while performing military specific tasks.

Literature on body weight values for use in exposure assessment was identified, and the mean and standard deviation for these studies are shown in table 6. The mean weight is presented for both genders combined as described by Brainard and Burmaster from the analysis of the Second National Health and Nutritional Examination Survey (NHANES II) data, and similar work by Brorby and Finley (Brainard, Burmaster, 1992; Brorby, Finley, 1992). One study specifically addressed Army personnel body weight. Gorden et al. assessed the weight of 1,774 men and 2,208 women in the Army. (Gordon, Churchill, Clauser, Bradmiller, McConville, Tebbets, Walker, 1989). In comparison, the

EPA's exposure assessment recommended value of 70 kg for a typical person falls slightly above the 25 percentile (68.04 kg) of the HRA body weight distribution. However, the 1997 EPA EFH mean body weight for males (17 to 51 years olds) is 78.2 kg.

DoD regulations and field manuals, used to assist individual soldiers, commanders, and leaders in many aspects of conducting operations, including public health, were also used for this research. The U.S. Army Regulation 611-*201, The Enlisted Career Management Field and Military Occupational Specialty (MOS)* identifies all enlisted military occupational skills with major duty description and physical demand class category (Department of the Army, 1995a, 1995b). Field Manual No. 21-10: *Field Hygiene and Sanitation* provides specific guidance on preventing disease and environmental injury during military operations (Department of the Army, 1988). The Military Occupational Specialty (MOS) Physical Task List and the Soldier's Manual of Common Tasks, Skill Level 1 provided specific time activity information (Department of the Army, 1978, 1990).

The Soldier's Manual of Common Tasks, Skill Level 1 contains common tasks for Army soldiers that are essential to conducting military operations. They represent the skill sets that will provide the soldier the ability to fight, survive, and win in combat. These are common basic tasks to all soldiers regardless of MOS. However, in addition to the soldier common tasks, there are task sets particular to each MOS.

Data set	(>18 yr.) Mean (kg)	SD (kg)
NHANES II (Brainard, Burmaster, 1992)	71.0 (Both Sexes)	15.9
Brorby and Finley (1992)	72.0 (Both Sexes)	15.9
Gordon et al. (1989)	78.75 (Men)	11.0
EPA EFH (1997)	77.6 (Men)	13.3

Table 6: Comparison of Adult Body Weight Estimates

CHAPTER 4 MATERIALS AND METHODS

4.1 Air Sampling Procedures

Environmental sampling conducted during deployment in the Former Yugoslavia is the most comprehensive environmental sampling in a DoD deployment operation. Specifically, air, water, and soil samples were evaluated for a variety of chemical contaminants. Samples were obtained and analyzed in accordance with appropriate EPA methodological guidelines. Ambient air sampling to identify unknown substances was done in the Former Yugoslavia deployment location in an attempt to estimate exposure from scenario evaluation.

Ambient air concentrations of benzene were measured during the U.S. military deployment to the Former Yugoslavia from 1995 to present (Appendix B). Table 7 summarizes the volatile organic sampled chemicals. Convenience ambient air monitoring occurred at 16 encampment locations in the U.S. Sector, a European U.S. military base, and a logistical/staging location.

CATEGORY & COMPOUND	N	% DETEC	CONCENTRATION (μ/m^3) Maximum	Mean	ACGIH (μ/m^3)	EPA (μ/m^3)
Benzene	206	72	106.9	5.22	3.20×10^4	60
Toluene	262	71	352.9	12.0	1.88×10^5	420
Decane	279	53	136	6.0	3.50×10^4	--
m&p-Xylene	273	51	273.9	9.71	4.30×10^5	7,300
Carbon tetrachloride	255	47	9.21	1.31	3.10×10^4	0.12
1,1,1-trichoroethane	261	39	7.42	1.12	1.90×10^6	1000
1,2,4,-trimethylbenzene	280	38	67	4.0	1.20×10^5	6.20
Hexane	252	32	131.7	10.2	1.76×10^5	210
o-Xylene	283	29	99.74	5.88	4.34×10^5	7,300
Methylene chloride	206	25	665	35.5	1.74×10^5	3.8
Naphthalene	266	23	7.14	1.98	5.20×10^4	--
Ethylbenzene	286	23	68.51	4.65	4.34×10^5	1,100
Isooctane	293	14				
1,3,5-trimethylbenzene	294	13				
Cyclohexane	289	13				
Methychloromethane	298	12				
n-propylbenzene	304	7				
Cyclopentane	317	6				
Styrene	318	4				
Tetrachloroethene	311	4				
isopropylbenzene	296	3				
p-isopropyl toluene	310	3				
Trichloroethene	320	3				
n-butylbenze	309	2				
Chloroform	318	1.5				
methyl tertbutylether	221	1.5				
sec-butylbenzene	317	1				
1,3-dichloropropane	322	1				
Chlorobenzene	322	1				
1,2-dichloropropane	321	1				
1,4-dichlorobenzene	318	<1				
1,2-dibromoethane	322	<1				
chlorobenzene	322	<1				
1,1,2-tetrachloroethane	322	<1				
1,2,4-trichlorobenzene	321	<1				
Bromodichloromethane	209	<1				
c-1,3-dichloropropene	323	<1				
t-1,3-dichloropropene	322	<1				
1,2,3-trichlorobenzene	321	<1				
1,1-dichloroethane	322	<1				
Dibromochloromethane	292	<1				
bromochloromethane	322	<1				

Table 7: Volatile Organic Chemicals Sampled

Ambient air VOC sampling was conducted continuously for three 8-hour periods over 24 hours, for two weeks at each location. The location at each campsite was selected to represent common exposure areas for all members and did not interfere with the daily military activities, or hinder the accomplishment of the military mission. Locations selected were considered suitable to identify ambient chemicals to which personnel may be exposed (e.g., center of an encampment).

A modified EPA Toxic Organic (TO-1) Ambient Air Monitoring Method using Carbosieve 300 sampling tubes was employed. The EPA TO1 method is a generalized protocol for collection and determination of certain organic compounds. (Winberry, Murphy, Riggan, 1988). This method employs a Tenax GC (poly(2,6-Diphenyl phenylene oxide)) tube, and determination is by GC/MS techniques. Use of the Supelco Carbosieve allows for an efficient sampling of a broader spectrum of organic compounds: from vinyl chloride to naphthalene. The sampling method is provided in a written protocol (Appendix C).

All samples were air transported to the United States for analysis. These samples were analyzed at the U.S. Army Center for Health Promotion and Preventive Medicine, Analytical Spectrometry Division, Aberdeen Proving Grounds, Maryland. The procedure followed is an EPA modified TO1, consisting of a thermal desorption/purge-and-trap/gas chromatographic/mass spectrometric steps. Appendix D is the standard operating procedure for analysis of volatile organics. Field blanks, trip blanks, and laboratory blanks were employed throughout all environmental sampling activities for quality control purposes (Appendix C and D).

4.2 Detection Limit and Nondetects

STATA® 5 was used for the statistical analysis of the benzene air sampling results (Stata, 1977). The ambient benzene concentrations were analyzed by total aggregate samples for the deployment, by individual camps, and then by region. A nondetect level of 0.25 ug/m^3 was calculated in accordance with EPA guidelines described below, and included in all of the following statistical analyses (Smith, 1991).

Exposure assessments often have data below the limits of detection referred to as censored data. Analytical detection limit (DL) is where the analyte is present, and its reported concentration is an estimate reliably distinguished from zero (Helsel, 1992). Simply omitting information below the limits of detection is inappropriate because it may mask uncertainties about potential levels of undetected risk.

Censored data are generally handled one of several ways. (1) Assign non-detects the value of the DL, which is conservative and produces a mean concentration biased high (Helsel, 1992) (2) Assign non-detects as zero, which assumes all undetected chemicals are absent (Helsel, 1992). (3) Assign non-detects as half the detection limit, which assumes that the average of the values is between the detection limit and zero; a uniform distribution of samples below the detection limits (Helsel, 1992). (4) Assign nondetects as the DL over the square root of two, which assumes non-highly skewed distribution (Helsel, 1992). (5) Employ mathematical techniques developed by Hald, which use information of the normal distribution (Hornung, Reed, 1990). The method selected depends on scientific judgment about the significant health, the proportion of non-detects, how the treatment of non-detects will affect the risk estimates, and whether a database is sufficient to support statistical analysis.

EPA Region III RBC (1997) $\mu g/m^3$	Highest 8 hr sample $\mu g/m^3$	Benzene at a hazardous concentration: 10^{-6} risk or hazard quotient of 1 (If no, assume non-detects are zero)	Sample taken down-gradient/adjacent to detectable concentration (If no, assume non-detects are zero)	Sample Plausibility Physical-chemical characteristics and other similar contaminants (If no, assume non-detects are zero)	Will non-detects equal DL/2 significantly influence quantitative risk estimates? (If no, assume non-detects are DL/2)	yes, use statistical methods to estimate concentrations below the DL
0.22	**106.19** →	**Yes** →	**Yes** →	**Yes** →	**No**	

Figure 10: Decision Process for Nondetects

The detection limit for benzene is $0.5\mu g/m^3$, and non-detects will be assumed as DL/2 from the EPA decision outlined in figure 10. According to this procedure, the contaminant must meet several criteria to reach this conclusion. First, benzene is identified at multiple sites and at concentrations exceeding the risk-based concentration of $0.22\mu g/m^3$. It is assumed that elevated benzene concentrations were measured at deployment locations down gradient from source. Benzene ambient concentration levels have plausibility based on physical and chemical characteristics of other site-related volatile organic compounds detected. While the statistical methods for estimating values between the DL and zero, such as those described by Hald and Gilbert are available, these procedures are recommended for compounds which significantly impact the risk assessment as described by the EPA decision path (Helsel, 1992; Gilbert, 1978). This is not likely the case for the ambient levels of benzene determined in this study. When Hornung compared methods, the dl/2 method is warranted over the $dl/\sqrt{2}$ method when data are highly skewed (Hornung, Reed, 1990). The decision is to assume non-detects equal DL/2.

4.3 Characterization of Exposure Groups: PDF Development

It was hypothesized that risk estimates calculated with military specific input parameters will be similar to those risk estimates calculated with EPA default parameters. Current deployment risk assessments are based upon the assumption that deployed populations are similar to the general population in exposure parameters. This assumption may result in over- or underestimation of the risk. Differences in the calculated risk could be partially attributed to limited or inaccurate knowledge of input distributions

characterizing the military population.

Individual dosimetry is ideal for evaluating exposures. However, this is not currently feasible in a military deployment. Failing monitoring of each individual soldier with personal dosimetry, deployment exposure estimation through exposure scenario evaluation requires the characterization of exposed subpopulations. Data collection procedures, methods, and availability of population exposure characteristics influence the development of the exposure cohorts.

As the first attempt to identify, characterize, and link specific military populations' characteristics for probability simulation of deployment risk estimates, the research provides useful insights and increased confidence in deployment risk assessment. Distributions of ventilation rates, body weights, time activity, and exposure duration are used to construct an overall distribution of exposure for the total deployed population and subpopulations.

Estimating the potential dose received from airborne contaminants requires knowledge of the concentration of the contaminants in the air, the amount of time a person spends in the contaminated environment, and the amount of air that person breathes while in the contaminated environment. This information is necessary in developing the exposure cohort, which can be constructed in several ways, depending on the available information and purpose.

Figure 11 illustrates the approach in establishing exposure cohorts. First, Military Occupational Specialties (MOS) and Career Management Fields (CMF) that participated in the deployment were identified. The occupational physical demand rating for each MOS, which is based on DoD fitness for duty requirements, was identified and evaluated.

Each MOS is qualitatively and quantitatively defined by physical demand level. Ventilatory rate categories were developed from U.S. Army exercise physiology data of active duty military personnel, and EPA ventilatory rating categories. This information was used to construct estimates of duty day ventilation rates for each of the CMFs.

Deployed exposure cohorts were further characterized using self-reported time activity surveys, doctrinal work/rest cycle schedules, and off duty ventilatory ventilation categories. Further characterization of exposure cohorts included body weight and exposure duration. Table 8, a compilation of the input parameters, identifies and describes the parameter distributions. These receptor parameters describe the physical characteristics of the individual and population.

The EPA point estimates and distributions are derived from the EFH handbook. The following sections detail the development of the exposure cohorts and PDFs for this research. All probabilistic calculations were done on an IBM-compatible desktop computer running Microsoft Excel and the Crystal Ball simulator (Microsoft Excel, 1997).

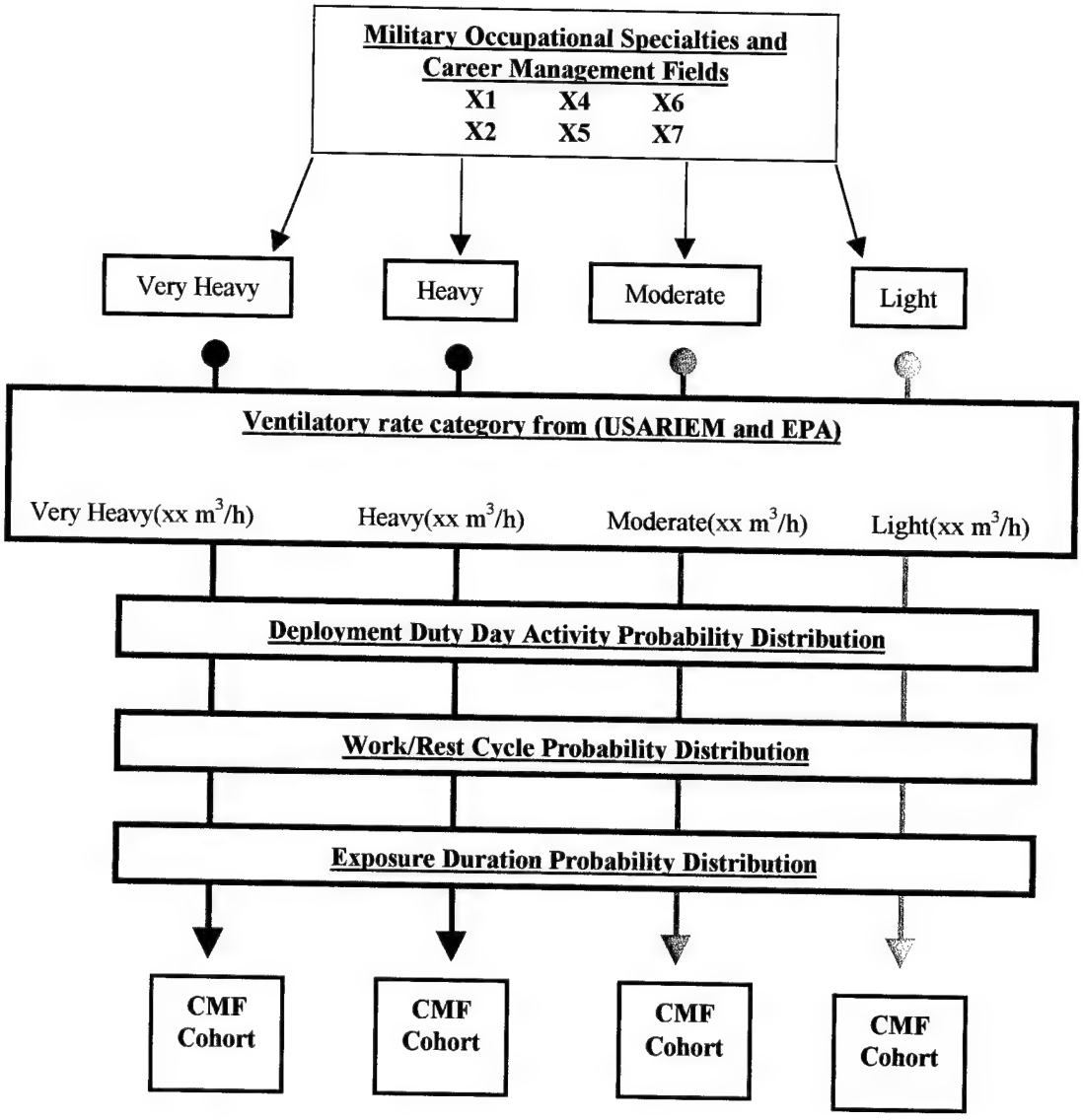


Figure 11: Establishing Deployed Exposure Cohorts

INPUT VARIABLE	UNITS	EPA POINT ESTIMATE	EPA'S EFH DISTRIBUTION	DEPLOYMENT DISTRIBUTION
Hazard Quotient	Unitless	1.0	1.0	1.0
Reference Dose EPA EPA & ACGIH	$\mu g/m^3$	17.1	17.1	17.1 CMF Dependent
Inhalation, adult (IRA_a)	m^3/d	20 15.2	General Population: Lognormal, X = 16.15, SD=6.26 Outdoor Workers: Lognormal, X = 31.2, SD = 3.1	Lognormal Distributions CMF dependent
Body weight (BW_a)	kg	70	Lognormal, X=78.5, SD=13.5	Normal, X= 76.6, SD = 12.15
Averaging Time, noncarcinogens (At_n)	days	365	350	Exposure Frequency x Exposure Duration
Exposure Frequency (EF_r)	days	350	350	365
Exposure Duration ED_{tot}	Years	1	1	Triangular Distributions
Benzene Concentration	µg/m3	Site 95% Tuzla (4.68) 1st Brigade (14.01) 2nd Brigade (1.54)	All lognormal Tuzla (X = 3.29, SD = 3.85) 1st Brigade (X = 8.27, SD = 20.20) 2nd Brigade (X = 1.10, SD = 1.26)	

Table 8: Summary of Input Variables

4.3.1 Deployed Soldiers' Inhalation Rate Estimation

Ventilation rates control the transport of airborne contaminants to the respiratory tract and are a fundamental component of inhalation exposure assessments. Therefore, inhalation exposure assessments require consistent estimates of ventilation rates for the population during the period of interest. For practical reasons, ventilation rates recommended for use in exposure assessment calculations are based on relatively small sample sizes, measured over short periods on individuals performing a variety of tasks in varying physical intensities.

While long term inhalation rates are controlled primarily by the amount of oxygen an individual consumes through the metabolic conversion of nutrients to energy, short term inhalation rates are more influenced by activity (Layton, 1993). Estimations of long-term ventilatory rates are developed through extrapolation from exercise physiology studies measuring a variety of physiological parameters on test subjects. Relevant measurements obtained during the exercise and resting periods include heart rate, breathing frequency, oxygen consumption, and body weight. Most frequently, expired-minute ventilations (Ve) are measured on subjects performing various physical tasks in both the laboratory and the field. This data is used to establish aggregate daily inhalation rate categories, such as those for adult males and females, children, occupations, and physical activity levels, as a product of the amount of air breathed for each time-activity performance.

Ventilation categories for cohorts are established from an estimation of the typical daily activities for that particular subpopulation. However, measurements of physiological parameters for all physical activities are unlikely to be available. Increasingly, investigators

are developing probability distributions for daily ventilation rates for use in risk assessment. (Brorby, Finely, 1993; Finely, Scott, Paustenbach, 1993; Beals, Funk, Fountain, Sedman, 1996). I developed daily ventilation distributions for deployed military member occupational groupings. Development of distributions for daily ventilation rate of deployed subpopulations incorporated 1) Ve measured in soldiers during performance of various military-specific physical tasks, 2) military occupational specialty physical demand ratings, 3) Soldier self reported time-activity during deployment, and 4) DoD work/rest cycle doctrine.

Physiological parameters of soldiers under laboratory and field physical and psychological stressors used in this study is based on research conducted at the USARIEM (Patton, Murphy, Bidwell, Mello, Sharp, 1995; Mello, Jones, Vogel, Patton, 1986; Knapick, Patton, Ginsberg, Redmond, Madeleine, Tharion, Vogel, Drew, 1987). Patton et al. assessed physiological demands on soldiers performing military-specific tasks. Mello et al. assessed the physical activity intensity during infantry combat-simulated operations. Knapick et al. evaluated heart rate on soldiers performing continuous field artillery operations and measured sleep during the military operations.

4.3.2 Assigning CMF's Activity to Ventilation Categories

Quantifying inhalation exposure necessitates identifying physical activities, the associated ventilation rates associated with those activities, and the time spent in each activity (Funk, Sedman, Beales, Fountain, 1998). Inhalation rates associated with specific activities have been characterized for distinct populations by several investigators. (Finley, Proctor, Scott, Harrington, Paustenbach, Rice, 1994; Droz, Fernandez, 1977; McKone,

Bogen, 1991). However, limited data are available on populations with activities that may result in high ventilatory rates over extend time during daily activities, such as physically intense activities of military deployments.

Military tasks were selected from the Military Occupational Specialty (MOS) Physical Task List and the Soldier's Manual of Common Tasks, Skill Level 1. These physical tasks are the basis of the physical requirement standards for the military occupational skills discussed above. Therefore, the physiological parameters measured in performing these specific activities are directly relevant for use in a time-time activity analysis to be applied in a deployment exposure assessment.

Comparing the ventilatory rates measured by Patton to those of the EPA indicate that soldiers' inhalation rates while performing military specific tasks span the EPA ventilatory categories. Soldiers have a wide range of military tasks with differing physical demands and ventilation rates while performing these tasks. These tasks were rank ordered by V_e and than categorized according to California Air Resource Board daily breathing rates and breathing rates of outdoor workers recorded by Shamoo et al. (Shamoo, Johnson, Trim, Little, Linn, Hackney, 1991). Appendix E shows the equilibration of the USARIEM-measured ventilatory rates for military specific tasks with EPA and Shamoo et al. ventilatory categories.

Based on specific duties, closely related skill sets, and military career progression, MOSs are grouped into CMFs. CMFs are groups of MOSs that are closely related in job activities. CMFs provide a career progression from enlistment through retirement for enlisted and officers. Soldiers are theoretically capable of assignment in any MOS in a specific CMF. These soldiers are most likely to have similar exposure patterns and work

activity patterns when compared with soldiers outside of the particularly CMF. Physical demand ratings of light, medium, moderate, heavy, or very heavy were assigned to each CMF MOSs/CMF were assigned an appropriate EPA ventilatory rate category (m^3/h).

4.3.3 Identification of Deployed Subpopulations

US Army Regulation *611-201, The Enlisted Career Management Field and Military Occupational Specialty (MOS)* identifies all enlisted military occupational skills with major duty descriptions, and physical demand class categories. U.S. Army Regulation *611-211, Officer Career Management Field and Military Occupational Specialty*, is the officer equivalent of the enlisted regulation. The physical demand class categories are the linking mechanism between duties required of that MOS and physical capacity required in performance of those duties. For this study, it also is the link in defining exposure cohorts in the deployed forces, based on estimations of daily inhalation rate. The defense manpower database was used to identify the different MOSs deployed to Bosnia. Appendix F is a list of military specialties deployed to Bosnia with the physical demand categories identified in these regulations.

4.3.4 Ventilation Rate limiting Assumptions

4.3.4.1 Work/Rest Cycle

Military commanders are ultimately responsible for unit personnel health. To help provide direction to commanders in the field, the DoD provides guidance in the form of field manuals. Field Manual No. 21-10: *Field Hygiene and Sanitation* assists individual soldier, commanders, and leaders in preventing disease and environmental injury during

military operations (Department of the Army, 1988). Chapter 3 of this manual provides guidelines in the implementation of work-rest cycles and water intake in order to prevent heat casualties. Command emphasis during military deployments usually result in mandatory and supervised adherence to these guidelines.

Table 9 identifies the work-rest cycle time limitations and temperature criteria. The Wet Bulb Globe Temperature Index is the guide for making preventive medicine recommendations when hot weather conditions are hazardous for the soldiers. With this information, decisions can be made regarding soldier activity in hot weather. Measurements are to be taken in a location that is the same as, or closely approximates, the environment to which personnel are exposed.

Administration for the implementation of the work-rest cycles is dependent on ambient temperature and humidity. The guidance provides for an hourly breakdown of the amount of minutes spent at work and at rest that allows for continuous military operations with minimization of heat stress casualties. According to the Field Manual, rest is defined as minimal physical activities. Work-rest cycles obviously affect ventilation rate for a deployed soldier and must be considered in development of the daily ventilation distribution.

The area of deployment in the Former Yugoslavia has a temperate climate with cold winters and hot and humid summers, similar to seasonal variations in Pennsylvania or Maryland. Therefore, the full work-rest cycle range has a probability of being implemented throughout the year. A probability distribution function was established for the number of minutes spent at a work level ventilation category for each of the CMFs.

For every 8 hours of duty performance, 1 hour is assumed to be spent for meals,

which will be calculated at a sedentary rate. A triangular distribution with the parameters of 0.20 (minimum), 0.62 (likeliest), and 0.87 (maximum) percent of hour spent in the work level ventilation was established. These represent work-rest cycles with an additional 13 percent subtracted to insure 1 hour for meals every 8 hours. The time not spent in the work ventilatory category for each hour is assumed to be at a sedentary ventilation level. For example, a duty day of 10 hours could consist of 6.2 hours at the work ventilatory rate for that CMF group, 2.5 hours at sedentary ventilation rate, and 1.3 hours spent at a sedentary ventilation rate for meals.

Criteria (WBGT Index ^{0}F)	Water Intake (quarts/hour)	Work/rest Cycle (Minutes)
78^0-81.9^0	At Least 1/2	Continuous
82^0-84.9^0	At Least 1/2	50/10
85^0-87.9^0	At Least 1/2	45/15
88^0-89.9^0	At Least 1/2	30/30
90^0 & above	At Least 1/2	20/40
Adapted from Field Manual No. 21-10: Field Hygiene and Sanitation		

Table 9: Work-Rest Cycle

4.3.4.2 Physiologic Capacity Limitations

While military members are physically conditioned, high levels of physical activities are not inexhaustibly sustainable. According to Erb and others, individuals can function at 25 to 40 percent of maximal aerobic capacity for a workday. (Erb, 1981; Blink, 1962; Bonjer, 1952). Given the age and physical conditioning of the military population, and the nature of deployment demands, this study assumes that a soldier's work capacity could conceivably be sustained at a level of 40 percent of maximal capacity during the entire deployment.

Using observations by Patton, an hourly work ventilation rate distribution, physiologically plausible for the highest ventilation category (upper level bound at 40% of measured Ve max values), was estimated. This lognormal distribution has a mean of 3.20 m3/hour with a high-end range limit of 4.10m3/hour. These values represent slightly less then 40 percent of the Ve_{max} values recorded by Patton et al. (Patton, 1995).

4.3.5 Soldier Body Weight and Ventilation Correlation

The U.S. Army Health Risk Appraisals (HRA) database contains health and anthropometric information on military members in the U.S. Army. The database is maintained by the U.S. Army Medical Surveillance Activity. The data set consists of 423,953 military member health assessments conducted from 1990 through 1996.

I conducted statistical analysis and constructed a histogram on the data set using SAS® 6.0 (SAS, 1989) (Appendix G). Visual inspection of the histogram suggests a normal distribution. The data was tested against a normal distribution using a Kolmogorov-Smirnov goodness-of-fit test (Table 10). I determined a normal distribution

for body weight with a mean of 76.6kg and a standard deviation of 12.15. A minimum weight of 47.62kg, and a maximum weight of 106.59kg were obtained from the HRA and used as bounding values. Body weights for a population are relatively stable, and these measurements are believed to be a good approximation of deployed members' body weight.

Ventilation is positively correlated with body weight: as body weight rises, ventilation rate increases (MacMillan, Reid, Passmore, 1965). Using data from the California Air Resource Board Study of ventilation rates, Beals et al. applied a Pearson's correlation coefficient to measure the linear relationship between Ve and body weight. Beals identified a significant correlation of Ve with body weight in adult males, women, and in children by activity level (Beales, Funk, Fountain, Sedman, 1996). For this study, Beals' et al correlation coefficients for adult males are applied for the different activity categories (Table 11).

These correlations are applied in the Monte Carlo analysis to estimate the joint distribution of the variables. Any input variables that have a high degree of correlation must be accounted for in the Monte Carlo analysis. Ignoring correlations can bias the Monte Carlo calculations. (EPA, 1995). In comparison, the EPA's exposure assessment recommended value of 70 kg for a typical person falls slightly above the 25^{th} percentile (68.04 kg) of the HRA body weight distribution.

N	Median kg	Mode kg	Mean kg	Standard Deviation kg	Variance	Kurtosis	Skewness	Kolmogorov-Smirnov
423,953	77.11	72.57	76.6	12.15	718.1	0.66	0.068	0.0301 ($P < 0.01$)

Table 10: Soldier Body Weight

Activity Level	Correlation Coefficient	Deployment Activity Level category
Low	0.52	Sleep, sedentary
Mod	0.72	Light, medium
High	0.73	Heavy
Adapted from Beals et al, 1996.		

Table 11: Correlation Coefficients for Body Weights and Ventilation Rates

4.3.6 Time Activity

Exposure duration, frequency of exposure, and chemical concentration are variables used to calculate average daily dose (EPA, 1986). Estimation of time activity distributions at various ventilation levels is used to establish inhalation exposures in populations (Ott, 1989; Robinson, 1989). Development of time activity probability distributions in these studies included information on the time spent and location of each activity, often collected via diaries or time sheets at the hour, half-hour, or even finer level of detail. Similarly, this study identifies distinct activity groups, and uses them to estimate daily ventilation rates based on broad time activity categories.

Quantification of inhalation exposures necessitates knowledge of the time spent by individuals doing various activities. No time-activity study analysis during a military deployment was identified. Information collected by the U.S. Army Department of Operational Stress Research on time spent on and off duty for each CMF provides the only available time-activity assessment during the military.

A self reported time activity data and analysis by Campbell et al provided a time activity measurement during this deployment (Cambell, Ritzer, Valentine, Gifford, 1998). Using the self-reported time activity data collected by Campbell et al, CMF daily activity categories were determined. Distributions are estimated from self-reported surveys of 5,088 deployed military personnel. The written survey, based on convenience sampling (Unit Commanders' discretion), was done by the U.S. Army Department of Operational Stress Research, Walter Reed Army Institute of Research, in three phases: Jun-Jul 1996; Oct-Nov 1996; Mar-Apr 1997. The purpose of the survey was to identify specific stressors and their sources affecting soldiers and soldiers' mechanisms and ability to cope

with operational stress.

Each soldier was asked to record the average number of hour slept and the average number of hours worked over the past week. The frequency and cumulative distribution of hours slept and hours worked along with statistical analysis are presented in Appendix H. The data is analyzed by total deployed and then by CMF.

Throughout the deployment, a "war–time posture" was maintained, which includes a 7-day week. This level of activity is considerably different from non-deployment environment. For example, over 35% of soldiers surveyed reported sleeping 5 hours or less per day, and on average soldiers worked a 12-hour duty day. This information is similar to sleep data collected by Knapick, who reported 5.5 as mean hours of sleep in the military deployment exercise environment.

Comparisons of the means for the CMFs' time activity hours were made using analysis of variance and Kruskill–Wallis tests. Normality was assessed with histograms, a skewness-kurtosis statistic, and a Shapiro-Wilks or Shapiro-Franconia normality test (Siegal, Castellan, 1988). For the hours worked and hours slept in the various CMF where normality could not be assumed, a Box-Cox transformation was employed.

A visual inspection of plotted hours worked for the total samples indicates a skewed distribution. The skewness/kurtosis test identified an other than normal distribution ($P > 0.01$). A Shapiro-Franconia test indicated the same result ($P>0.01$). ANOVA results indicate that the CMFs within the total sample come from different populations ($P>0.01$). Because the sample indicates an other than normally distributed population, a Kruskal-Wallis test was completed. This test also indicates that the separate CMF's observations may have been selected from different populations.

A visual inspection of plotted hours slept for the total sample indicates a normal distribution. A Shapiro-Franconia test indicated normally distributed data ($P>0.1$). ANOVA results indicate that the individual CMFs came from different populations ($P>0.000$), as does the Kruskal-Wallis test of equality of populations.

Once the CMFs had been identified as distinct groups in terms of time slept and time worked, data were examined to determine which theoretical distribution most closely reflected the data. For most of the CMFs' time activities, normal distributions best described the activity groups, while log normal described the remainder. Table 12 identifies the distributions used in this research. For the deterministic technique, a deployment day is estimated at 12.25 hours of military specific duties minus 1 hour for lunch and a total of 1 hour for breaks (sedentary level activity), 2.89 hours of off duty light activity, 2.89 hours of off-duty sedentary activity, and 5.9 hours of sleep.

CMA	Hours of work distribution (mean, SD)	Hours of sleep distribution (mean, SD)
Administration	Normal (12.47, 2.76)	Lognormal (5.87, 1.29)
Air Defense	Normal (13.46, 2.63)	Normal (5.69, 1.14)
Armor	Lognormal (11.17, 3.15)	Normal (5.84, 1.11)
Artillery	Normal (11.06, 3.49)	Normal (6.24, 1.15)
Aviators	Normal (12.01, 2.90)	Normal (6.08, 1.02)
Engineers	Normal (12.10, 3.55)	Normal (5.87, 1.11)
Infantry	Lognormal (11.54, 3.40)	Normal (5.83, 1.14)
Logistics	Normal (12.32, 2.95)	Lognormal (5.85, 1.17)
Maintenance	Lognormal (10.93, 3.19)	Normal (5.79, 1.22)
Medical	Normal (13.94, 3.35)	Normal (6.10, 1.16)
Military Intelligence	Normal (12.32, 2.74)	Normal (5.98, 1.07)
Military Police	Lognormal (13.56, 2.63)	Normal (5.87, 1.07)
Signal	Lognormal (12.31, 3.16)	Normal (5.89, 1.27)
Transportation	Normal (11.14, 3.05)	Normal (6.15, 1.20)

Table 12: Time Activity Distributions

4.3.7 Deployed Daily Ventilatory Rate

Daily ventilatory rate distributions were developed by applying the ventilatory rates for the military physical demand categories with the reported duty day time-activity pattern, work-rest cycle distribution, and ventilatory rates for the different activity categories. Figure 12 shows the algorithm for estimating daily ventilation rates for the deployed subpopulation. CMF physical activity levels were equilibrated with Ve rates determined by Patton et al and EPA physical demand category ventilatory rates. Work duty Ve was then calculated using the Ve times the reported hours of work for the specific CMF.

Sleep and sedentary activity ventilation rates are calculated at 0.4 m^3/h. For sleep Ve, the rate is multiplied by the mean hours of sleep reported by each of the CMFs. The total daily sedentary Ve is calculated by adding the work time and sleep time and dividing by two. These hours are then multiplied by 0.4 m^3/h. Then the sedentary time during work (rest cycle) is multiplied by 0.4 m^3/h and added to the sedentary ventilatory daily rate to establish a total daily sedentary Ve. Light activity for each day is calculated at one-half of the remaining hour in a 24-hour period minus work and sleep hours. These hours are then multiplied by at light activity ventilatory rate or 1.1 m^3/hour. The total Ve rates for each of the categories are then added for a total daily ventilation rate. Using Microsoft Excel, feedback calculations were place in appropriate cells to ensure one day consisted of 24 hours.

Using the above input assumptions and distributions, daily ventilation rates for each of the time activity categories are provided in Table 13. These input parameters developed a distribution for daily ventilation for each of the CMFs. A chi-square

goodness-of-fit test and the nonparametric Kolmogorov-Smirnov test did not reject the null hypothesis that the CMF daily ventilations are lognormally distributed. This study employed these daily Ve in the hazard quotient calculation. Summary statistics of the daily ventilatory probability distributions are provided in table 14.

CMF	Distribution and Parameters
Administration	Lognormal, X = 16.55, SD = 1.80
Air Defense	Lognormal, X = 25.53, SD = 4.53
Armor	Lognormal, X = 29.29, SD = 6.07
Artillery	Lognormal, X = 25.76, SD = 8.12
Aviation	Lognormal, X = 21.35, SD = 7.72
Infantry	Lognormal, X = 29.86, SD = 6.51
Logistics	Lognormal, X = 30.89, SD = 6.50
Maintenance	Lognormal , X = 29.04, SD = 5.90
Medical	Lognormal, X = 19.05, SD = 2.67
Military Intelligence	Lognormal, X = 21.26, SD = 3.20
Military Police	Lognormal, X = 21.80, SD = 3.32
Signal	Lognormal, X = 21.19, SD = 3.10
Transportation	Lognormal, X = 29.45, SD = 6.21

Table 13: Daily Ventilation Distribution Parameters

	TRIALS	MEAN	MEDIAN	SD	VARIANCE	SKEWNESS	KURTOSIS	COEFFICIENT OF VIABILITY	RANGE	
									Min	Max
Administration	10000	16.55	16.48	1.80	3.22	0.26	3.21	0.11	10.19	26.47
Air Defense	10000	25.53	25.23	4.53	20.54	0.40	3.01	0.18	14.17	45.20
Armor	10000	29.29	28.59	6.07	36.84	0.67	3.52	0.21	15.40	58.85
Artillery	10000	29.22	28.62	6.43	41.40	0.57	3.27	0.22	14.53	56.82
Aviation	10000	21.35	20.84	7.72	59.67	0.44	3.01	0.36	14.45	58.18
Engineering	10000	24.88	24.50	4.60	21.14	0.48	3.04	0.18	13.92	44.97
Engineers	10000	24.88	24.50	4.60	21.14	0.48	3.07	0.18	13.92	44.97
Infantry	10000	29.86	29.18	6.51	42.35	0.53	3.07	0.22	14.73	59.17
Logistics	10000	30.89	30.31	6.50	42.24	0.47	2.98	0.21	13.95	60.52
Maintenance	10000	29.04	28.42	5.9	35.84	0.64	3.49	0.21	14.40	58.70
Medical	10000	19.05	18.87	2.67	7.15	0.40	3.01	0.14	12.26	30.93
Military Intelligence	10000	21.26	21.02	3.20	10.24	0.50	3.38	0.15	13.08	37.89
Military Police	10000	21.80	21.61	3.32	11.05	0.37	3.07	0.15	11.46	38.19
Signal	10000	21.19	20.94	3.10	9.59	0.46	3.27	0.15	12.49	35.59
Transportation	10000	29.45	28.84	6.21	38.58	0.53	3.19	0.21	14.81	62.23

Table 14: Summary of Daily Ventilation Distributions

4.3.8 Exposure Duration

The Defense Manpower Data Center tracks, among other information, data on the movement of Army personnel, including military personnel deployed in Bosnia. Relevant to this research, the database maintains fields on time spent in Bosnia, categorized by MOS. Appendix I presents the average, minimum, and maximum time spent in the deployment area. The exact location of individual soldiers or groups of soldiers (camp or region) are not available. Therefore, camp and region will be ignored as an exposure estimation class, and the members will be grouped by CMF and time spent in theater only.

The precise time in Bosnia or time at a particular camp location for individual soldiers is not available. Considering the level of uncertainty available in this data, triangular distribution was chosen for the distribution. Triangular distribution is a conservative estimate used when such uncertainty exists in the data. This conservative perspective is the result of essentially a truncation of a normal or lognormal distribution, resulting in greater selection of values in the tails of the distribution (Brosby, Finely, 1993). Table 15 identified the distributions for CMF exposure duration. For this research, averaging time is assumed to equal 365 days per year.

Career Management Field	Minimum (yr.)	Likeliest (yr.)	Maximum (yr.)
Administration	0.010	0.62	1.65
Air Defense	0.003	0.38	1.48
Armor	0.020	0.65	1.88
Aviation	0.001	0.63	2.16
Engineers	0.010	0.64	1.97
Field Artillery	0.005	0.62	1.80
Infantry	0.003	0.48	2.12
Logistics	0.003	0.61	1.90
Maintenance	0.005	0.63	2.03
Medical	0.005	0.67	2.10
Military Intel	0.001	0.61	2.11
Military Police	0.001	0.66	1.90
Signal	0.001	0.61	2.12
Transportation	0.005	0.68	2.19

Table 15: Exposure Duration

4.4 Inhalation Reference Doses (RfD_i)

For the purpose of providing "risk-framing" reference, this study compared two RfD_i values in evaluating deployment exposure risk estimates. Figure 12 shows the RfD_i formula. First, the EPA RfD_i designed to protect the general population of the U. S. was used as the most conservative value. An inhalation reference dose believed to be more representative of a health worker population, living and working in the same environment, was then calculated. This RfD_i value was derived from time-weighting the EPA and the American Conference of Government Industrial Hygienist Threshold Limit Values.

4.4.1 Environmental Protection Agency RfD_i

The RfD_i used in this study is derived from a provisional subchronic inhalation reference concentration (RfC) for benzene. This value was obtained from a LOAEL of 5.7 mg/m^3 from a study on mice completed by Baarson (Baarson, Snyder, Albert, 1984). An uncertainty factor of 100 applied for inter- and intraspecies dose adjustments and interspecies variability results in the subchronic RfC of $6x10^{-2}$ mg/m3. Using this value, and the EPA default values for daily ventilation rate and body weight, a 17.1μg/kg/day RfDi is derived.

$$RfDi = \frac{RfC_i \times \text{Ventilation Rate}}{\text{Body weight}}$$

Figure 12: Inhalation Reference Dose Formula

4.4.2 American Council of Government Industrial Hygienists RfD_i

A modified RfD_i was calculated using the American Conference of Government Industrial Hygienists Threshold Limit Value - Time Weighted Average (TLV-TWA) for benzene. The TLV-TWA is the time-weighted average concentrations for an 8-hour workday and a 40-work week at which workers can be repeatedly exposed without adverse health effects (ACGIH, 1992).

Since 1977, the TLV-TWA has been 10ppm (32 mg/m^3) (ACGIH, 1992). However, increasing epidemiological and toxicological evidence of hematapoetic and carcinogenic health outcomes in working populations has resulted in a revision of the TLV-TWA from 10ppm to 0.1ppm (0.32mg/ m^3) (ACGIH, 1992). A combined RfD_i was calculated using both the RfC and a modified ACGIH-TLV concentration value for each CMF. Figure 13 shows the EPA-ACGIH time weighted RfD_i calculation.

The ACGIH-TLVs are effect-based values that consider a working population exposed 8-hrs/day, 5 days/week, 50 weeks/year for 30 years (ACGIH, 1992). Importantly, the ACGIH values consider a 16-hour daily break in exposure that may be important in the disposition of substances. Published mathematical methods for extrapolating TLVs for varying work schedules are available (Paustenbach, 1994). However, extrapolations for a full 24-hour period were not identified.

For this research, I used a TLV modification method first described by Brief and Scala (Brief, Scala, 1975). Brief and Scala developed calculations for determining TLV Reduction Factors (RF) for modified workdays and modified workweeks. I used the 7-day workweek formula (figure 14) for this research.

I first calculated the total number of work and non-work hours per week for each

CMF and applied this information in calculating a reduction factor for each CMF (Figure 15). The next step was to calculate new benzene TLVs for each CMF by multiplying the TLV by the reduction factor. In the last step, I combined the TLV concentration with the EPA RfC_i to determine the RfD for the Career management fields. I applied standard default daily ventilatory rates of $1.8m^3/h$ (EPA outdoor worker ventilation rate per hour) for duty hours and $0.85\ m^3/h$ (general population ventilation rate per hour) for non-duty hours. Table 16 shows the deployment modified RfD_is.

$$RfD_{iMD} = \frac{(\text{Modified TLV} \times 1.8 m^3/h \times T_{hr}) + (6.0 \times 10^{-2} mg/m^3 \times 0.83 m^3/h \times T_{hrs})}{70kg}$$

Figure 13: EPA – ACGIH Time-weighted Calculation

Reduction Factor =

(40 hrs ÷ weekly work hours) x (weekly non-work hrs ÷ 128)

Brief and Scala (1975)[137]

Figure 14: Seven-day TLV reduction factor calculation

Adjusted TLV =

Reduction factor X TLV

Figure 15: TLV Adjustment

Career Management Fields	Weekly work hours	Weekly non-work hours	TLV Reduction Factor	New TLV (ppm)	Deployment Modified RfD_i
Deterministic	85.7	82.25	0.30	0.030	38.71
Air Defense	94.22	73.78	0.24	0.024	34.71
Armor	78.19	89.81	0.36	0.036	42.21
Artillery	77.42	90.58	0.37	0.037	42.88
Aviators	84.07	83.93	0.31	0.031	39.16
Engineers	84.70	83.30	0.31	0.031	39.33
Infantry	80.78	87.22	0.34	0.034	41.15
Logistics	86.24	81.76	0.30	0.030	38.77
Maintenance	76.51	91.49	0.37	0.037	42.44
Medical	97.58	70.42	0.23	0.023	33.52
Military Intelligence	86.24	81.76	0.30	0.030	38.57
Military Police	94.92	73.08	0.24	0.024	33.92
Signal	86.17	81.31	0.30	0.030	38.70
Transportation	77.98	90.02	0.36	0.036	40.65

Table 16: Deployment Modified RfD_i

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Air Sampling Analysis

Of the total 206 samples, 149 were above the detection limit of 0.5 ug/m^3 for benzene (Table 17). The minimum benzene concentration is 0.55 ug/m3 and the maximum concentration is 106.19 ug/m^3. The mean is 3.99$\mu g/m^3$ with a 99 % confidence that the population mean lies somewhere in the interval from 2.12 to 5.87$\mu g/m^3$ (Table 18).

Analysis indicated that the benzene concentration is other than normally distributed. The skewness of 7.48 indicates a heavier right tail (symmetrical = 0), while the kurtosis of 67.27 also indicates a heavier distribution tail area (Gaussian = 3). The skewness-kurtosis statistic null hypothesis that the samples did come from a normally distributed population can be rejected. A Box-Cox transformation for benzene was completed. The results indicate that log transformation distribution of benzene resembles a theoretical normal curve (Skewness =0.06; Kurtosis = 1.9).

Mean	3.99
Geometric Mean	1.14
Standard Deviation	10.36
Variance	107.25
Std. Err.	0.72
99% CI	2.12 – 5.87
Skewness	7.48
Kurtosis	67.27
Observations	206

Table 17: Summary of benzene Concentration

Camp	Mean	Standard Deviation	Frequency
Demi	2.15	1.41	10
Guardian	2.80	3.18	27
Sarajevo	4.32	2.51	20
Eagle	1.95	1.42	33
Ugljevic	1.18	0.51	8
Gentry	0.99	1.15	5
Kime	2.54	3.68	12
Linda	0.72	0.87	12
Lisa	0.52	0.85	10
Lukavic	5.58	5.61	25
McGovern	11.65	24.49	31
Germany	0.405	0.44	8
Ali	2.59	0	1
Angela	2.38	0	1
Hungary	2.59	0.37	3
Total	3.99	10.36	206

Table 18: Summary Statistics of Benzene by Camp

5.1.1 Encampments

The between camp benzene concentration mean was tested to determine if the independent encampment samples might have come from the same population. The nonparametric Kruskal-Wallis one-way analysis of variance (ANOVA) by ranks was used to assess the null hypothesis that the population means are equal. The Kruskal-Wallis test results (P = 0.001) indicated a significant difference in benzene concentration by camps and that the difference is greater than would be expected if the samples came from the same population.

The next step was an examination of the data by region within the deployment theatre. Three regions -- 1st Brigade, 2nd Brigade, and Tuzla Valley -- represent relatively close clusters of U.S. military camp in 3 different geographical and industrial development areas (Table 19). The 1st Brigade area is located approximately 50 miles north of the Tuzla Valley in a more rural area than Tuzla Valley. The 1st Brigade camps included Kime, McGovern, and Gentry. The Tuzla Valley region is a more industrialized region than either the 1st or the 2nd Brigade areas. The Tuzla valley area camps included Alicia, Eagle, Angela, Bedrock, Guardian and Lukavic. The 2nd Brigade area is approximately 43 miles south of the Tuzla Valley, and is a more mountainous terrain. The 2nd Brigade area consisted of camps Demi, Lisa, and Linda. Sarajevo, Ugljevic, Germany, and Hungary camps, geographically separate from these regions, are not included in this study.

REGION	CAMPS INCLUDED	REGION DESCRIPTION
1st Brigade	Kime	About 50 miles north of Tuzla Valley encampment region. Rural plateau environment.
	McGovern	
	Gentry	
Tuzla Valley	Alicia	Valley region. The most industrialized of the three regions.
	Eagle	
	Angela	
	Bedrock	
	Guardian	
	Lukavic	
2nd Brigade	Demi	About 50 miles south of the Tuzla Valley encampment region. The most mountainous region of the three
	Lisa	
	Linda	

Table 19: Region Description

For each of the regions, a descriptive statistical summary was done. A Kruskal-Wallis statistic on each of the potential regional groupings determined if camp means are comparable and could be grouped. The non-parametric test was also completed because the sample size in several areas is very small, and the nature of the distribution was assumed lognormal, but is not known exactly. Therefore, the non-parametric test provided another way to compare the regions and camp means, with fewer assumptions about the population distribution. Deployment exposure assessment will include Tuzla, and the 1st and 2nd Brigade as separate locations. Alicia and Angela, having only one test result each, will not be included in the risk assessment because of incomplete benzene air sampling. The individual regional analyses are described below.

5.1.2 Tuzla Valley

Tables 20 and 21 show the summary statistics for ambient benzene concentration for the Tuzla Valley camps. Sixty-eight (79%) observations were above the detection limit. The minimum benzene concentration for Tuzla Valley is 0.62 $\mu g/m^3$ and the maximum concentration result is 23.2 $\mu g/m^3$. The mean is 3.28 $\mu g/m^3$ with a 99 % confidence that the population mean lies somewhere in the interval from 2.18 to 4.39 $\mu g/m^3$.

Benzene sampling results appears to be other than normally distributed. The skewness of 2.99 indicates a heavier right tail, while the kurtosis of 14.28 indicates a heavier distribution tail area. The skewness/kurtosis following transformation indicates that transformed data much more closely resemble the theoretical normal.

ANOVA and Kruskal-Wallis statistics tested the Tuzla Valley camps means. The

ANOVA statistic shows that the hypothesis of equal means cannot be rejected ($P = 0.05$). There is high probability that the camp means come from the same population. This same conclusion is reached with the Kruskal-Wallis test. Therefor the camps were aggregated for analysis.

Camp	Mean	Standard Deviation	Frequency
Guardian	2.80	3.18	27
Eagle	2.00	1.41	33
Lukavic	5.66	5.66	24
Alicia	2.59	0	1
Angela	2.38	0	1
Total	3.29	3.85	86

Table 20: Summary Statistics of Benzene: Tuzla Valley Camps

Tuzla Valley Summary	
Mean	3.27
Geometric Mean	1.85
Standard Deviation	3.85
Variance	14.83
Std. Err.	0.42
99% CI	2.18 - 4.40
Skewness	3.04
Kurtosis	14.70
Observations	86

Table 21: Summary Statistic for Benzene: Tuzla Valley.

5.1.3 1st Brigade Area

Statistical analysis of benzene concentrations in the 1st Brigade area is presented in tables 22 and 23. There were 35 (73%) observations above the detection limit in the 1st Brigade area camps. The minimum sampling result for this area is 0.55 $\mu g/m^3$ and the maximum sampling result is 106.2 $\mu g/m^3$. The overall mean for the region is 8.26 $\mu g/m^3$ with a 99 % confidence that the population mean lies somewhere in the interval from 0.44 to 16.09$\mu g/m^3$.

For the 1st Brigade area, benzene concentration is other than normally distributed. The skewness-kurtosis statistic null hypothesis that the samples did come from a normally distributed population can be rejected (P>0.000). The skewness/kurtosis following transformation indicates that transformed data much more closely resemble the theoretical normal curve.

Assessment of the means of the 1st Brigade area camps was performed with an ANOVA and the Kruskal-Wallis test. According to the ANOVA statistic (P = .294) and the Kruskal-Wallis test (P = 0.37), there is a greater than chance probability that the means do come from the same population. The hypothesis of equal means cannot be rejected. The camp benzene concentration can be aggregated for the risk analysis.

Camp	Mean	Standard Deviation	Frequency
Gentry	0.99	1.14	5
Kime	2.54	3.68	12
McGovern	11.66	24.50	31
Total	8.27	20.20	48

Table 22: Summary Statistic for Benzene: 1St Brigade Camps

Statistical summary 1St Brigade	
Mean	8.26
Geometric Mean	1.64
Standard Deviation	20.20
Variance	407.86
Std. Err.	2.91
99% CI	0.44 - 16.10
Skewness	3.76
Kurtosis	17.10
Observations	48

Table 23: Summary Statistical for Benzene: 1St Brigade

5.1.4 2nd Brigade Area

For the camps in the 2nd Brigade area, there were 12 (34.5%) observations above the detection limit in three different camps (Tables 24 and 25). The minimum concentration result for 2nd Brigade Area is 1.56 $\mu g/m^3$ and the maximum concentration result is 4.9 $\mu g/m^3$. The overall mean for the region is 1.10 $\mu g/m^3$ with a 99 percent confidence that the population mean lies somewhere in the interval from 0.49 to 1.71 $\mu g/m^3$.

Further analysis indicates that benzene concentration may be from an other than normally distributed population. The skewness is slightly more heavily right tailed, while the kurtosis indicates a slightly heavier distribution tail area. The null hypothesis that the samples did come from a normally distributed population can be rejected.

In assessment of the camp benzene concentration of the 2nd Brigade region, the ANOVA statistic shows that the hypothesis of equal means can be rejected (P = .003); however, the hypothesis of equal variances cannot (P = .201). The Kruskal-Wallis test results (P = 0.0232) do not agree with the one-way findings of significant difference in benzene levels by camps in the 2nd Brigade region at the .01 level of significance. Based on the nonparametric analysis, benzene concentrations from the different camps were aggregated for the analysis.

Camp	Mean	Standard Deviation	Frequency
Demi	2.15	1.42	10
Linda	0.72	0.87	12
Lisa	0.52	0.85	10
Total	1.10	1.26	32

Table 24: Summary Statistics for Benzene: 2nd Brigade Camps

Benzene statistical summary 2nd Brigade	
Mean	1.10
Geometric Mean	0.58
Standard Deviation	1.29
Variance	1.58
Std. Err.	0.22
99% CI	0.49 - 1.71
Skewness	1.29
Kurtosis	3.90
Observations	32

Table 25: Summary Statistics for Benzene: 2nd Brigade

In summary, each of the regional benzene concentration distributions is best characterized by a lognormal distribution. For Tuzla and the 1st and 2nd Brigades, the null hypothesis of equal means of the camps cannot be rejected. The three regions will represent the different ambient benzene levels for the deployed population. Table 26 shows the probability distribution parameters for the benzene concentration in the three different regions. According to EPA Guidelines the more conservative arithmetic mean will be used as the distribution means in the Monte Carlo simulations (EPA,1995, 1997).

The concentrations identified in the three different regions are similar to those that may be found in a typical urban environment in the United States (Table 27). The ambient concentrations are considerably lower than those measured at hazardous waste sites. (Bennett, 1987). The mean levels were also lower than the personal exposure determined by the TEAM study. (Wallace, 1989).

REGION	DISTRIBUTION CHARACTERIZATION
Tuzla	Lognormal; X = 3.29, SD = 3.85
1st Brigade	Lognormal; X = 8.27, SD = 20.20
2nd Brigade	Lognormal; X = 1.10, SD = 1.26

Table 26: Region Benzene Distribution Parameters

Location	Ambient Benzene Concentrations ($\mu g/m^3$)
Tuzla	X= 3.86, SD = 3.85
1st Brigade	X= 8.27, SD = 20.20
2nd Brigade	X=1.1, SD = 1.26
Staten Island, NY	X=14.1, SD = 21.1
San Francisco, Ca	X=8.3, SD = 4.1
Stinson Beach, Ca	X=1.2, SD = 1.24
Personal Exposure	X=15

Table 27: Comparison of Ambient Benzene Concentrations

5.2 EPA Hazard Quotient Estimates

The study hypothesis is that the RME calculated HQ value would exceed the upperbound 95% of the HQ distribution estimates using military input distributions in a Monte Carlo simulation. Reasonable maximal exposure estimates using both 20 and 15.2 m^3/d ventilatory rates were calculated according to EPA guidelines (EPA, 1988,1997). Probability simulations of risk estimates for the three deployment regions used EPA input variables for the general population and outdoor workers, and military specific input variable for each CMF. Separate simulation analysis was then completed for the 1st Brigade area using the combined EPA/ACGIH RfD_i. Distribution graphs are presented in Appendix J.

Results of the risk estimations are shown in table 28 and 29. Deterministic and simulation hazard quotient estimates did not exceed the noncancer hazard assessment level of 1.0 for benzene. Both the mean and upper 95 percent of simulation-derived risk distribution estimates for military deployed subpopulation in all regions were less than the noncancer hazard assessment level of 1.0 for benzene. Hazard quotient mean values ranged from 0.01 for the Administrative CMF located in the 2nd Brigade region to 0.19 for Logistics CMF in the 1st Brigade region. Simulation distribution's upper 95 percent values ranged from 0.04 for administrative CMF in the 2nd Brigade region to 0.74 for logistics CMF in the 1st Brigade region.

Reasonable maximal exposures estimates using EPA values did not exceed the upper 95 percent of the simulation estimates for any of the deployed subpopulations, but are similar to the simulation means. Reasonable maximal exposures estimate using 20m^3/d daily ventilation rate parameter closely reflected the mean simulation estimates for CMFs

with physical demanding military occupational skills. RME estimate using 15.2m^3/d daily ventilation rate parameter was reflective of the mean simulation estimates for CMFs not having physical demanding military occupational skills.

Risk estimate distributions obtained using EPA suggested input parameters for outdoor worker daily ventilation are similar to the estimate distributions of deployed CMFs with higher physical workload requirements for all three regions. Likewise, the probability distribution obtained from using the EPA suggested input parameters for the general population closely matches the distribution of the CMF identified as not being physically demanding.

NONCANCER HAZARD QUOTENT	Tuzla		1st Brigade		2nd Brigade	
Deterministic (RME) using EPA Parameters						
(20 m^3/d)	0.08		0.23		0.02	
(15.2 m^3/d)	0.06		0.18		0.02	
Monte Carlo Simulation EPA Parameters	**Mean**	**95%**	**Mean**	**95%**	**Mean**	**95%**
General Population	0.04	0.12	0.10	0.37	0.01	0.04
Outdoor Workers	0.08	0.24	0.19	0.73	0.03	0.08
SIMULATION RESULTS - MILITARY SPECIFIC PAREMETERS						
CAREER MANAGEMENT FIELDS	**Average**	**95%**	**Average**	**95%**	**Average**	**95%**
Administration	0.04	0.13	0.10	0.39	0.01	0.04
Air Defense	0.07	0.20	0.16	0.61	0.02	0.06
Armor	0.08	0.31	0.18	0.70	0.02	0.07
Artillery	0.07	0.22	0.18	0.68	0.02	0.08
Aviation	0.08	0.24	0.19	0.72	0.03	0.08
Engineers	0.06	0.19	0.16	0.59	0.02	0.06
Infantry	0.08	0.23	0.19	0.71	0.03	0.08
Logistics	0.08	0.19	0.19	0.74	0.03	0.08
Maintenance	0.08	0.23	0.18	0.69	0.02	0.07
Medical	0.05	0.15	0.12	0.45	0.02	0.05
Military Intelligence	0.06	0.16	0.13	0.51	0.02	0.05
Military Police	0.07	0.19	0.14	0.52	0.02	0.06
Signal	0.06	0.16	0.13	0.51	0.02	0.05
Transportation	0.08	0.23	0.19	0.70	0.03	0.08

Table 28: Hazard Quotients Using EPA RfDi

NONCANCER HAZARD QUOTENT	1st Brigade	
Deterministic (RME) **EPA Parameters** (20 m^3/d) (15.2 m^3/d)	 0.23 0.18	
Monte Carlo Simulation **EPA Parameters** General Population Outdoor Workers	 **Average** 0.10 0.19	 **95%** 0.37 0.73
SIMULATION RESULTS **MILITARY SPECIFIC PARAMETERS**		
	EPA RfD_i (17.1 µg/kg/d)		**Modified RfD_i CMF dependent µg/kg/d**	
CAREER MANEGMENT FIELD	**Mean**	**95%**	**Mean**	**95%**
Administration	0.10	0.39	0.05	0.17
Air Defense	0.16	0.61	0.08	0.30
Armor	0.18	0.70	0.08	0.29
Artillery	0.16	0.61	0.06	0.24
Aviation	0.19	0.72	0.08	0.31
Engineers	0.16	0.59	0.07	0.26
Infantry	0.19	0.71	0.08	0.30
Logistics	0.19	0.74	0.09	0.32
Maintenance	0.18	0.69	0.07	0.28
Medical	0.12	0.45	0.06	0.23
Military Intelligence	0.13	0.51	0.06	0.22
Military Police	0.14	0.52	0.07	0.26
Signal	0.13	0.51	0.06	0.22
Transportation	0.19	0.70	0.08	0.29

Table 29: Hazard Quotients Estimates Using Combined RfDi

All HQ RME estimates and the upperbound 95% probability estimates were below 1.0, indicating soldiers were not likely exposed to ambient levels of benzene expected to present a noncancer adverse health effect. The highest RME was 0.23 for the 1st Brigade Area and the highest upperbound 95% value was 0.72. Subpopulations of soldiers with higher activity levels had HQs greater than soldiers with less physically demanding military occupations.

An HQ greater than 1.0 indicates that potential exposure is exceeding reference dose(s) for the chemical(s), and as the frequency and/or magnitude of exposures exceeding the reference dose increases, the probability of toxicity increases. A HQ of less than 1.0, as in the present case, indicates no risk of noncancer toxicity, even for susceptible individuals in the exposed population. However, it should not be concluded that all exposures greater than the reference dose would result in an adverse health outcome for the populations.

In summary, the RME derived non-carcinogenic hazard index for inhalation exposure to benzene at the three studied regions using EPA default input values were 0.08 for Tuzla, 0.23 for the 1st Brigade , and 0.02 for the 2nd Brigade. These estimates did not exceed the 95 percent upper-bound HQ values for any Career Management Field derived by probability simulation using military specific input distributions. Continuous exposures to benzene concentrations equal to or less than the RfD_i levels for no more than the specific time period should not result in any adverse health effects to the deployed member.

The combined EPA-ACGIH RfD_i shifts the HQ distribution curves to the left. As would be expected the HQ values are lower due to the higher exposure standard for a

health occupational workforce. The upper 95 % of the combined RfD_i exceed the RME vaults and falls slightly above the average HQ results using the EPA RfD_i.

5.3 Sensitivity Analysis

Sensitivity analysis examined the influence of input variables on the risk estimates. Sensitivity analysis identifies which input variables have the greatest effect on the estimate – which of the model inputs are most important. Relatively large changes in the risk estimates will occur from relatively small changes in the values used for these variables. A linear relationship between input variables and output risk estimates was measured using a rank-order correlation technique. The correlation coefficients measure the degree to which the input parameters and hazard quotient estimates change together. (Morgan, Henrion, 1990; NCRP, 1996). A rank correlation method was used.

A degree of confidence in the results of probabilistic analysis can be conferred from the results of the sensitivity analysis. When the most sensitive input variables are based on limited or uncertain confidence, the results of the output may be low. On the other hand, if the most sensitive variables are those with the most robust set of statistically valid or site-or population-specific data, a higher degree of confidence may be conferred. The first sensitivity analysis examines input variables used to construct the daily ventilation. The second examines those exposure variables used to calculate the HQ.

The sensitivity analysis examining the relationship between daily ventilation estimates used work/rest cycle, work hours, work ventilation, sleep ventilation, light activity ventilation, hours of sleep, and body weight under 14 workload assumptions in the estimation of daily ventilation rates. Table 30 shows the top three input contributors in

percent variability in the risk estimate. Individual sensitivity charts displaying the correlation coefficients between input variable and daily ventilation estimates are presented in Appendix K.

MODEL PARAMETERS	% VARIABILITY IN RISK CONTRIBUTED BY:		
	Work/Rest Cycle	Work Hours	Ventilation during Duty
Administration	33.1	21.4	15.7
Air Defense	56.8	29.5	7.7
Armor	45.5	25.5	11.9
Artillery	60.5	25.3	6.0
Aviation	65.9	10.3	11.1
Engineers	42.2	23.9	13.6
Infantry	43.7	31.4	10.2
Logistics	48.4	25.2	11.7
Maintenance	42.3	25.9	12.9
Medical	55.3	16.5	12.9
Military Intelligence	49.2	17.4	10.1
Military Police	53.3	16.9	9.1
Signal	48.5	15.7	11.3
Transportation	43.2	28.8	11.2

Table 30: Sensitivity Analysis: Daily Ventilation Rates

The relationship between the HQ estimates, daily ventilation, ambient benzene concentration, body weight, and time in theatre under the three different deployment locations for each occupational category was examined. Table 31 shows the percent variability in risk contributed by the benzene concentration and daily ventilation for each of the CMFs. Individual sensitivity charts are presented in Appendix L. Results indicate that the HQ is more influenced by the benzene concentration across all occupational categories. The approximation of variable contribution to HQ variance showed that benzene concentration contribution to HQ variance was higher when physiological workload was less.

MODEL PARAMETERS	% VARIABILITY IN RISK CONTRIBUTED BY:	
	Benzene Concentration	Daily Ventilation
EPA Population	99.7	0.3
EPA Worker	96.2	3.7
Administration	98.4	0.9
Air Defense	97.5	1.5
Armor	97.0	2.0
Artillery	94.6	4.4
Aviation	96.9	2.0
Engineers	97.4	1.6
Infantry	96.8	2.2
Logistics	96.9	2.0
Maintenance	97.0	2.0
Medical	98.1	0.9
Military Intelligence	97.9	1.1
Military Police	97.9	1.1
Signal	98.0	1.0
Transportation	97.0	2.0

Table 31: Sensitivity Analysis: Hazard Quotient Estimates

In summary, the overall population exposure was largely influence by ambient benzene concentration and the assumption of all members having rest periods throughout the duty day. Nevertheless, it is not known whether all subpopulations actually had the opportunity to participate in work/rest cycle activity, and at what level.

CHAPTER 6 STUDY CONCLUSION

Before the public scrutiny of the DoD's handling of adverse health effects suspected to have resulted from soldiers' Persian Gulf duties, deployment environmental exposure assessment did not receive much of military preventive medicine's attention. Preventive medicine policies and doctrines almost exclusively focused on infectious disease risks in a deployment situation. Only with the recent Joint Instruction on Deployment Medical Surveillance is deployment environmental exposure risk being considered in DoD policy and preventive medicine guidelines (DoD, 1997).

Characterizing and understanding exposures in a military deployment as a component of a comprehensive medical surveillance program is essential in evaluating and protecting soldiers' short and long term health risks. According to the NRC, *"Exposure assessment is an integral and essential component of environmental epidemiology, risk assessment, risk management, and diagnostic and intervention efforts..."* (NRC, 1991). Effectiveness of a comprehensive medical surveillance program that includes environmental health risks will depend on successful implementation of the NAS risk assessment paradigm. Successful implementation of the NAS paradigm will depend on effective and efficient exposure assessment components. Without exposure information critical to health risk evaluation, preventive medicine policy formulators and military

decision-makers responsible for protecting members' health will be at a distinct disadvantage.

Considerable challenges confront a DoD deployment exposure surveillance program. These challenges are similar to those being faced by other federal government agencies. Exposure analysis, as a relatively new field of scientific investigation, has a general scarcity of appropriate data (Wagner, Selevan, Sexton, 1995; Sexton, Selevan, Lybarger, 1992). Available data are generally insufficient to be of value to decision makers confronting policy formulation and regulatory decision-making. Sexton, Callahan, Bryant, Saint, Wood, 1995). National surveillance systems were designed to monitor regulatory compliance, and not populations, surveillance has occurred significantly removed from sites of human-contaminant interaction, adding further concerns about the limited available data.

As DoD implements an exposure and risk assessment program for deployments, it is in a unique position to contribute to resolving some of the issues of exposure assessment, which have far-reaching implications outside of DoD. Specifically, an exposure assessment program for military deployments has an opportunity to contribute to strengthening what is considered by some as the weakest link in the NAS risk assessment process (Burke, Tran, Roemer, Henry, 1993). Deployment exposure assessments will focus on monitoring at the point where human exposure occurs. Specifically, military deployment scenarios can usually be defined in terms of defined geographic location where well-characterized soldier populations will most likely live and work. Additionally, the DoD medical component maintains one of the most comprehensive medical surveillance programs in existence, which collects comprehensive medical information on all military

members. Finally, DoD can focus on health end point, and should not be constrained by state and national regulatory compliance issues. For these reasons, a DoD deployment exposure surveillance and analytical program could have far reaching implications for the field of exposure assessment.

This research constitutes the first step in the process of collecting, collating, and analyzing military specific exposure parameters and the evaluation of exposure assessment methodologies specific for military deployments. The techniques analyzed and applied in this study provide a theoretical and practical starting point for assessing potential doses for deployed populations, interfacing medical surveillance and exposure surveillance, and supporting policy development. In military deployments, as elsewhere, uncertainty and variability exist in the process of human health risk assessment. However, fully aware of the limitations of the assumptions made, and equations and models used, this research serves as the basis for the development of a framework for deployment exposure assessment.

Probabilistic risk assessment is an effective method of understanding the range of risks from environmental exposures in a deployment environment. Military decision-makers work in a comparative risk based decision-making environment. Therefore, they need to understand the range of risk for incorporation into deployment risk ranking and decision making. Probability techniques in deployment risk assessment can be a valuable tool for this purpose. Further research of military input parameters, exposure reference values, deployment uncertainty and variability, and medical surveillance linkages will affect the accuracy, reliability, and value of exposure assessments to deployments and the quality and values of information provided to decisions makers.

6.1 Variability and uncertainty

Health risk reduction and management are preventive medicine planning considerations before, during, and after deployment. Management or prevention options for environmental exposure risks during deployments may range from extensive to not practical, realistic, or an option. Throughout this risk continuum, a vital issue is the precision with which preventive medicine can characterize the distribution among soldiers of potential dose associated with the contaminant(s) exposures during the deployment period. Uncertainty and variability in assessing environmental exposure risks exist in all deployment environmental health risk assessments. However, deployment risk management and decision-making are possible with these uncertainties, as long as the uncertainties are taken into account.

One method to address uncertainty is the RME calculation, which compounds upper-bound estimates to theoretically project a conservative estimate of risk. However, the RME does not yield to understanding uncertainty in the estimate, or the ability to communicate uncertainty to the decision-maker. Therefore, risk assessors or decision-makers cannot separate uncertainty and variability, consider or suggest methods to reduce uncertainty, or effectively place the estimate in a comparable risk paradigm. Awareness and characterization of uncertainties provides a more credible, better-understood, and more useful risk assessment to risk managers (Whipple, 1986,1989). RME method is not optimal for military decision-makers in a competitive risk environment.

This research describes a general model for estimating potential dose from inhalation exposure during a military deployment and estimating the distribution of risk. This model includes parameters describing deployment inhalation rate estimates, exposure

duration, and ambient concentrations. For some input distributions, only the mean and variance parameters were available. Probability distributions could be fully determined and examined on several parameters. For others, expert judgment was applied. Estimating hazard quotients from exposure to airborne contaminants during a military deployment included daily inhalation rate, ambient chemical concentration, work/rest cycles, body weight, time in deployments, exposure duration, and time spent on activity as input parameters. Assessment of hazard quotient during deployment involves uncertainty around ambient concentrations, physiological demands, military activity pattern, and non-uniform exposure periods and susceptibility.

6.2 Source of uncertainty

The inherent heterogeneous nature of sampling ambient concentrations of airborne chemicals can present a large source of variability. The transport and distribution of a chemical into the environment is complex (Fries, Paustenbach, 1989; McKone, Daniels, 1991). Spatial-temporal components, inversion, conversion, and meteorological conditions contribute to the natural variability of air pollutant measurements. The use of area monitoring has been identified as an important source of uncertainty in assessing individual inhalation exposure to airborne chemicals (Lebert, 1995; Hatch, Thomas, 1993; Lebowitz, 1995).

Estimating potential dose using scenario models has limitations. Using area concentration values for estimating potential dose and human health risks from exposures assumes that dose can be approximated by the measurements taken at the sampling locations, and the sampling time period is representative of the time period of interest. The

sampling location, while selected as the location representative of the exposures to camp personnel, may be greater or less than for camp personnel in general. In addition, the ambient concentration may fluctuate throughout the deployment exposure period, such as seasonal fluctuation.

Detection limit of analytical methods also can contribute to uncertainty in exposure estimates. Models used to estimate non-detects, which are the result of limits of analytic method, contribute to uncertainty in the estimates of potential dose and subsequent risk estimates. Omitting information on non-detects conceals important uncertainties about potential levels of undetected risks, while assigning non-detects as DLs is a highly conservative approach producing a biased high mean concentration. Other statistical predictions of concentrations below the DL can be applied for compounds that significantly impact the risk assessment and for which data are adequate (Gilbert, 1987, Helsel, 1990). For this study, based on an EPA decision path, non-detects are reported as half the DL, which assumes that the average value of non-detects could be as high as half the detection limit.

An important source of uncertainty in this study lies in assigning daily ventilation estimates to CMFs. The daily ventilation rates were estimated from ventilation rates of selected soldier activities. These activities are basic to all soldiers, but are not inclusive of all activities. Although this process is subjective, differences between the ventilation levels facilitated the assignment of the military-specific activities to the EPA ventilatory categories. Additionally, the description of work level activities as contained in the military occupational skill categorization facilitated the assignment of CMF to specific ventilatory categories.

Another source of uncertainty is intrinsic to time-activity studies. Limitations of the studies, such as the soldier's memory of activities; inaccuracies in reporting; and respondent censorship represent concerns. Additionally, because detailed activity information was not collected, gross aggregating of activities by CMF also could contribute to the level of uncertainty. However, given the relatively rigidly structured activities of members during a deployment, the extent of the uncertainty may be minimal. In addition, it must be realized that the opportunity to collect detailed time-activity information in such an environment may never be practical.

6.3 Approaches to Limit Uncertainty

Decreasing sample variance through an increase in sample size could reduce uncertainty in the exposure estimates. Increasing frequency of sampling and an increased number of sampling locations could prove valuable. In large deployment areas, more samples could be collected to ensure representation of that deployment site.

Location of sampling sites within a camp could ensure better representativeness of ambient concentration within the site. These conclusions about potential human risks assume that ambient benzene exposures can be approximated by the measurements taken at the camp center. However, the camp data may significantly overestimate or underestimate average deployment location exposures to these chemicals. Ambient monitors located near source benzene may be greater than for the deployment location in general, thus overestimating exposures to benzene. On the other hand, the sampling site be in a relatively more "pristine" location; therefore, benzene exposures may be underestimated by the area sampling method.

Daily inhalation rate is an aggregate of the product of the amount of air breathed per minute for each activity and the number of minutes per day in that activity. Ventilation estimates were established based on the ventilation rates measured by Patton et al. in their study of the metabolic costs of soldiers' common tasks. The military tasks, selected from the Military Occupational Specialty (MOS) Physical Task List and the Soldier's Manual of Common Tasks, Skill Level 1, are the basis of the physical requirement standards for the military occupational skills. However, ventilation rates for many military activities have not been measured; therefore, ventilation levels were estimated for soldiers in certain CMF as a surrogate category of clusters of similar activities. A better understanding of physiological demands placed on soldiers doing military tasks would help reduce uncertainty in daily ventilator rates. The level of increased physical workload intensity in a deployed population may increase the probability of an occurrence and the severity of the adverse health effects because of increased respiratory rate resulting in an increased uptake of chemicals.

Estimates of the range of inhalation exposures in a population require an understanding of the variability of ventilation in the population. Variability in ventilation rates most likely are due to age, gender, physical activity, and physical capacity. For the deployed military members in a given MOS, inhalation rates are likely to be influenced by deployment specific conditions, the type or mission of the deployment, and the point of time in the deployment continuum.

Time-activity analysis could significantly contribute to the reduction in uncertainty in risk estimated for military operations. The time-activity assessment was based on the assumption that the majority of the duty day for a particular CMF is spent in a particular

ventilatory category, based on the job description. An analysis of more detailed time-activity assessment may yield different distributions of time spent in various ventilatory categories of physical activity.

Limited data is available for characterizing the military population for deployment risk assessment. This data could further reduce uncertainty in environmental exposure risk estimates, and identify subpopulations with different levels of risk. Characterization of the population, deployment environment, and reduction of levels of uncertainty identifies potential points of preventive medicine interaction.

Military deployments usually have a delineated beginning and end. However, these time periods do necessarily define the exposure duration for deployed individuals or subpopulations. Individual service members and units arrive and leave throughout a deployment period. Therefore, the exposure duration for an individual selected at random from the deployed population may be significantly less or greater than that characterized by the official beginning and end of the deployment operation. The exposure duration was estimated as a triangular distribution with the shortest, average, and longest time spent. For this analysis, the averaging time is the time over which the exposure effects are averaged, which is one year. The ability to obtain accurate hazard quotients from inhalation risks depends on the quality of the deployment air sampling design, the reliability of the analytical methods, and the estimation of the daily respiratory rate.

6.4 Policy Implications

Experiences in Vietnam and the Persian Gulf demonstrated the need for DoD to better assess deployment environments and to communicate environmental exposure risk

findings to military policymakers, commanders, military members, and the public. The concerns of many veterans from these experiences are the relationship between their deployment exposures and delayed onset health problems. DoD's inability to responsively communicate uncertainties, variabilities, and understanding of the adverse problems and suspected exposures is mainly due to the lack of data to which scientific rigorous standards can be applied. The lack of exposure and medical data underscores the need for a DoD focused deployment health surveillance, assessment, management, and follow-up capacity. DoD has yet to translate this recognized need into policy.

DoD lacks a strategic environmental policy for military deployments. Lack of a DoD strategic policy on deployment exposure surveillance and environmental risk assessment creates an unnecessary burden on preventive medicine assets and operational commanders, possibly endangers the health and safety of U.S. forces, places medical surveillance imperatives at risk, and expose the DoD to credibility issues from external criticism. An obstacle to the development of policy is the lack of a model for environmental exposure assessment and risk management of exposures during deployments.

Adapting DoD peacetime standards to deployment is inadequate. Environmental standards affecting U.S. military operations during peacetime are primarily designed for installation level, and reflect the same standards as those at the national and/or local civilian environmental protection levels. DoD demonstrates environmental stewardship worldwide by addressing the same set of standards and cost benefit decisions during peacetime operations. However, these standards for exposure assessment and risk estimates is inappropriate for use during military deployments, due primarily to the nature

of environmental regulatory decision making process in the United States, and the comparative risk decision-making framework in which military decision makers must work

Largely, complex cost-benefit analysis of economic and societal intervention costs and public health and environmental quality benefits have established environmental regulatory standards (Burke, Sexton, 1995). Intervention considerations such as site clean up, siting of waste disposal facilities, and permit approvals, among others, have been drivers of environmental policy formulation, although not necessarily characterizing and reducing exposures of public health consequences. Further, recent emphasis on regulatory standards setting and quantitative risk assessment dependent on point estimates has moved environmental decision-making even further away from public health and epidemiological and exposure analysis. This reliance on quantitative risk assessment process has, according to some authors, resulted in the discounting of exposure as a factor in the final risk assessment (Silbergeld, 1993). While the processes of establishing environmental regulatory standards have been beneficial to the improvement of environmental quality throughout the Untied States, they have also resulted in lack of knowledge development on characterizing human exposures (Sexton, Callahan, Bryant, Saint, Wood, 1995).

In a broad sense, environmental policy development challenges of divergent policy drivers facing the DoD are similar to those identified in other federal agencies involved in environmental health risk assessment (Sexton, Callahan, Bryant, Saint, Wood, 1995). Theoretically, preventive medicine's needs do not contrast with the military decision-makers. The military medical departments exist to support combat forces and to maintain and sustain the fighting forces (DoD, 1998). Both preventive medicine and military commanders share the common goal of reducing risk to military members -- a basic tenant

for military policy, training, and doctrine. However, preventive medicine's and commanders' needs and practical limitations in reducing risk to military members do often diverge. Frequently, preventive medicine and military commanders are not aware of the differing drivers that are shaping preventive medicine policy development. Table 32 compares DoD's and federal agencies' perspectives and forces on exposure assessment.

FEDERAL AGENCIES' PERSPECTIVES		DOD DEPLOYMENT PERSPECTIVES	
SCIENCE	POLICY	PREVENTIVE MEDICINE	OPERATIONAL FORCES
Understanding multimedia pathways & total human exposure	Legal requirements for media-specific source monitoring	Incorporating current scientific knowledge to understanding exposures specific to military member	Environmental Provisions contained in laws of war (Hague IV & Geneva Convention)
Evaluation of full spectrum of pollutant exposures, including mixtures	Limited list of regulatory substances or 'chemicals of the month'	In additional to traditional warfare agents, assess full spectrum of deployment pollutant exposures	Limited list of warfare substances or 'enemy chemical agent of choice'
Support for methods development and long-term status & trend measurement	Political & public demand for quick results - crisis response science	Operational & strategic evaluation fighting capacity, & forces' health from service entry to beyond discharge	Political demands for prevention of "gulf-war" like illness.
Expanded information about exposure related non-cancer endpoints	Regulatory emphasis driven by concerns about chemical carcinogens	Understand nature of combined occupational & environmental exposures to all health endpoints	Operational emphasis driven by concerns about ensuring a deployed healthy fighting force
Understanding of geographic variation & heterogeneity of exposures in the populations	Risk assessment-derived 'bright-lines,' point estimates to characterize risk and exposure	Recognizing differences in exposure among a highly mobile, healthy population.	Comparative risk decision-making with unique risks related to military activities
Sustainable support for advancing the state of the art of exposure sampling & analysis	Limited funding for new research initiates under existing framework	Support for sampling and analytical capability targeted to deployment exposure	Highly competitive environment for dwindling DoD resources
Adapted from Burke and Sexton, 1995			

Table 32: Environmental Policy Influencing Forces

While all of the DoD policy influences are individually important and need to be understood, there are two unifying themes for strategic environment policy development. These include a comparative risk-based framework and a population based public health focus. Decision-making before and during deployments is truly a comparative risk-based process. Military decision-makers go beyond considerations of medical information supporting the decision-making process. With this in mind, environmental policy for military deployments starts with a different reference point for balancing science and values in health risk assessments. This reference point is that risk-free operations will not be attained. Therefore, population-based exposure information is vital to policy process and preventive medicine management activities. Exposure surveillance activities cannot be based on ensuring compliance with peacetime regulatory intervention standards, but specifically and only for the purpose of understanding and evaluating soldier exposure with adverse health consequences for the identification of preventative actions.

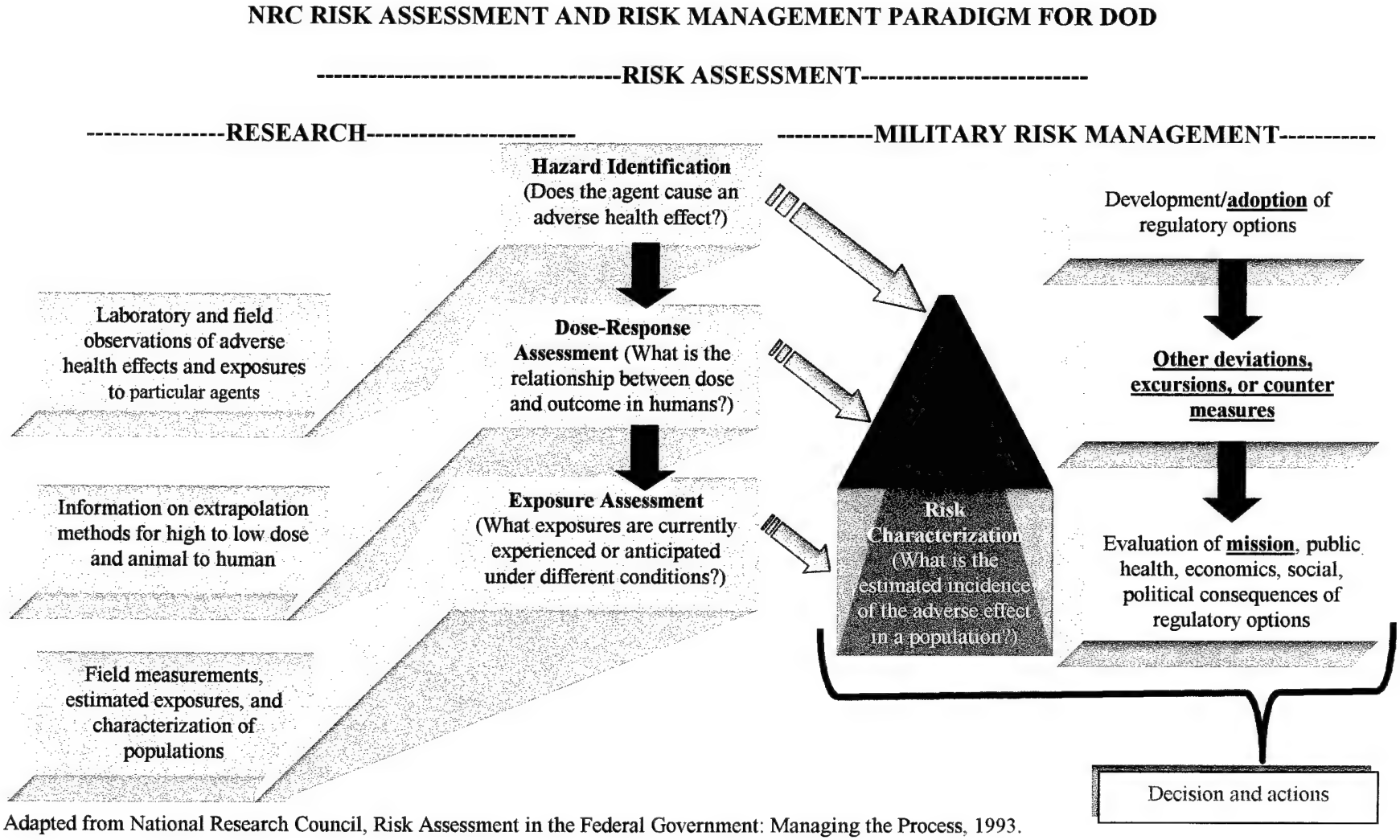
The level of any exposure assessment designed for evaluation of health effects must be determined by the medical surveillance information. The approach and level of detail of the exposure surveillance initiative depend on the strengths of the health surveillance program. A detailed, extensive exposure assessment program may be a significant waste of resources if it is not supporting a directed and detailed medical surveillance program. The deployment exposure surveillance program is then an extension of an effectual military public health foundation -- a population-based public health approach. Therefore, policy guidelines, instruction, directive, and resources must ensure both components develop together. Policy development should capitalize on the current and extensive military public health epidemiological capacity. This public health

perspective will draw upon the understanding of the incidence and prevalence of disease within the military population and the expertise and functional capabilities that exists.

The exposure surveillance goal then becomes to determine and articulate actual soldier exposures to hazards in the deployed environment. Understanding and estimating exposure to non-warfare chemicals during deployments involves determining who was exposed and to what chemicals, and at what concentration, frequency, and duration the exposure occurred. This exposure assessment process must be in a framework tailored for the specific mission goals and constraints, and still capture the most relevant data necessary for analysis, risk characterization, and support to the medical surveillance program. In other words, the exposure component of an environmental health risk assessment procedure must be integrated into the mission, be non-invasive to the mission, and provide information necessary to assess etiological factors of identified disease incidence and prevalence in the military population.

An effective DoD strategic environmental health policy will direct and ensure a population-based, exposure–related health assessment of deployed personnel. The goal is focused efforts to readily approach and understand deployment related health concerns of active duty members and veterans. However, even with a comprehensive environmental and medical surveillance program in place, knowledge gaps in exposure assessment, hazard identification, dose-response, complex mixtures, and cumulative exposure risks, among others, will affect the outcome of the risk characterization. Therefore, success in meeting policy goals and in supporting policy development is dependent on the quality of information gathered and analyzed. Exposure surveillance is essential to characterizing risk and reducing knowledge gaps during deployments.

The exposure surveillance program is part of a formal preventive medicine NAS risk assessment paradigm specific for military deployments (NRC, 1983; Burke, Tran, Shalauta, 1997). Figure 16 is an adaptation of the NAS paradigm. This process incorporates all factors in preventive medicine's purview in support of the military decision-maker. It allows for the risk management flexibility needed in a military operation setting. This process is transparent to commanders and military members. The process must be available for scrutiny and analysis by others within and outside of DoD. Increased transparency of the process for evaluation of health risks to military members during active duty service will be of considerable benefit not only to the service members, but also to the DoD.



Adapted from National Research Council, Risk Assessment in the Federal Government: Managing the Process, 1993.

Figure 16: Risk Assessment Paradigm for DoD Operation

6.5 New directions

A recommended direction for DoD assessment of environmental health risk assessment during military deployments is away from the use of a point estimates and towards the use of probabilistic techniques. Deterministic techniques should not be solely relied upon to assess or predict the soldier health risks. The use of probabilistic techniques provides a characteristic of the range of the risks, and allows the decision-maker to be informed of the underlying assumptions and uncertainties in the full range of the risk estimate. Probabilistic techniques will require a more robust risk assessor-risk manager interaction, but very importantly is not contrary to the commander's risk management fundamental principals. The medical risk assessors must fully appreciate and understand the essential aspects of risk management, described in table 33, to be effective in force health protection.

Essential Military Risk Management Elements

- Risk management assists the commander in-
  - Conserving levels and resources and avoiding unnecessary risks
  - Making an informed decision to implement a course of action
  - Identify feasible and effective control measures where specific standards do not exist
  - Provide reasonable alternatives for mission accomplishment

- Risk management does not-
  - Inhibit the commanders' and leaders' flexibility and initiative
  - Remove risk altogether, or support a zero defect mind set
  - Require a GO/NO-GO decision
  - Sanction or justify violating the law
  - Remove the necessity for standard drills, tactics, techniques, and procedures

Field Manual 100-14, Risk Management, 1998

Table 33: Principles of Military Risk Management

Environmental exposure surveillance will be a component of preventive medicine in all future military deployments. It requires development of the capacity to assess environmental exposure risks on members' performance and health. An overarching direction for the deployment surveillance system is one not driven by the need to control pollution and monitoring sources. The starting premise of this research is that deployment surveillance is primarily concerned with forecasting the distribution of deployed members' exposures. Exposure data linked to health risk characterization will be the foundation for biomarkers application, epidemiology study design, and preventive medicine intervention activities, supporting the evaluation of relationships of possible adverse health effects before, during, and after deployments.

The development and implementation of a deployment exposure surveillance program requires a conceptual framework supporting the overall DoD medical surveillance program. This program collects, archives, and analyzes data to suggest plausible health outcomes and mechanisms of action effecting military members. The core framework components for exposure surveillance program, include defining and characterizing the population, designing deployment monitoring, and the centralizing, archiving, and linking of the data.

An important direction for the DoD is the characterization of the military population and deployment personal activities in the framework of exposure analysis. The characterization of the population includes information collected but not centralized or analyzed for exposure assessment purposes. For example, standard questionnaire and health risk appraisal information routinely collected on military members contains data for exposure input parameters. This information could be collected, analyzed, and used to

construct probability distributions for use in exposure assessment models.

Personal activities have been shown an important function of assessing personal exposures to ambient chemical contaminants (Lioy, 1990; Ott, 1990). This study demonstrated that activity levels as measured by hours of work and hours of sleep in deployments are different from what may be expected elsewhere. However, a finer level of time-activity analysis could be achieved and greatly contribute to understanding of deployment exposures on a microenvironmental scale. This information contributes to characterizing the distribution of risks to the deployed members and is invaluable in exposure scenario calculations, which combine estimates of concentrations with estimates of human activities to provide an estimate of exposure for a particular situation.

Continued exploratory analysis of existing DoD data sets, as was done for this research, could allow analysts to determine potential occupational, military unit, service, and geographic variability of exposure. Deployment regions, and location within a region, are likely to vary with regard to the presence and concentration of ambient chemicals, and possibly with the activities of the military members. Understanding of the variability in personal exposures across and within deployment regions needs to be determined. Military population and deployment-specific probability distribution functions should be developed and used by DoD.

DoD will need to direct deployment monitoring. The level of monitoring, the extent of coverage, identification of chemicals to be assessed, and the pathways of exposure need to be considered. A deployment exposure surveillance program will use procedures to gather information about the magnitude and extent of soldiers' exposure. EPA defines three exposure assessment procedures: point-of-contact, scenario evaluation,

and estimation by reconstruction of internal dose (Federal Register, 1992). Point-of-contact evaluates the exposure in close proximity to the interface between the person and the environment. Estimation of exposure by reconstruction involves the use of biomarkers to determine past exposures. Estimation of exposure from scenario evaluation uses medium concentration and population information to determine exposure. All of these procedures need to be considered for future military deployment. The right combination of procedures and the level of effort will be determined by factors including the suspected or identified risks, type of mission, and preventive medicine involvement in deployment planning and execution phases.

A recommended new direction for DoD assessment of environmental health risk assessment during military deployments is away from the use of a point estimates and towards the use of probabilistic techniques. The point estimate approach for military deployments should be used only in the initial screening of the deployment area. Deterministic techniques should not be solely relied upon to assess or predict the soldier health risks. The use of probabilistic techniques provides a characteristic of the range of the risks, and allows the decision-maker to be informed of the underlying assumptions and uncertainties in the full range of the risk estimate.

6.6 Research Recommendations

This research identifies several areas of possible research needs for a comprehensive exposure surveillance program. These research areas are similar to those identified by other policy, risk assessment, exposure assessments and environmental research scientists involved in the environmental sciences. Figure 17 was adapted from

Sexton specific for deployments, and outlines the research data requirements and potential cost for a comprehensive deployment exposure assessment program (Sexton, Gong, Bailat, Ford, Gold, Lambert, Utell, 1993). A deployment exposure surveillance capability has significant database requirements. Within DoD, some are available but not investigated, while others need to be developed. Accurate ambient concentration and military populations' intake distributions require efforts toward collecting and analyzing additional information to develop the data needed for exposure assessment during deployments. The following recommendations are made:

- Improve the quality of known ambient chemical risks by improving methods to identify sources of exposure risk potential before deployment
- Improve quality of military population exposure characterizations. Where input parameters information is not available, identify a research need to develop the data set.
  - Military ventilation rates over a extended period
  - Deployment time-activity studies
- Develop capabilities linking surveillance exposure data collected and the medical and health data being collected
- Develop capabilities for a longitudinal exposure history over the military members' active duty deployment experience
- Identify and consider use of specific biomarkers as pre- and post deployment exposure measures

COST AND ABILITY TO ESTIMATE EXPOSURE RISKS	DATA NEEDS AND ANALYSIS	EXPOSURE ASSESSMENT	RESEARCH AND DEVELOPMENT
Generally lower cost with limited accuracy	Emissions sources, accidental releases, point source contamination	Medical intelligence of the deployment environment	Environmental intelligence assessment methodology
	Deployment environmental monitoring: air, water, soil, and food	Deployment environmental monitoring	Environmental sensors, personal dosimetry
	Personal monitoring and deployment health status: inpatient and outpatient events	In-theater medical treatment facility	Biomarkers of exposure (field diagnostic capabilities)
Generally higher cost with increased accuracy	Medical surveillance: biomarkers, environmental epidemiology	Comprehensive "cradle to grave" medical surveillance, environmental epidemiology	Biomarkers of effect (data integration and analysis)
Adapted from Sexton et al., 1993			

Figure 17: Deployment Exposure Surveillance Continuum

A successfully integrated deployment environmental risk assessment program will support medical surveillance initiatives, and contribute to the overall health risk assessment, which defines and characterizes potential risks by minimizing uncertainties and accounting for variabilities in the deployment evaluation. The ability to link health and environmental data is vital to understanding the relationships between levels of exposure, pathways of exposure, and eventual health outcome.

Glossary

Boxplot: Graphical representation showing the center and spread and outliers of a distribution.

Casualty: A member lost from a military operation because of death, wounds, injury, or illness.

Coefficient of variation:

An estimate of relative standard deviation. Standard deviation divided by mean.

Comprehensive Military Medical Surveillance (CMMS):

A process that provides a capability to provide decision-makers with the status of the health, fitness, and medical readiness of the force, and with options for detecting, assessing, and countering health threats.

Confidence Interval: The range within which one has a given level of confidence that the range includes the true value of the known parameter.

Correlation, Correlation Analysis:

Correlation analysis is an investigation of the measure of statistical association among random variables based on samples. Widely used

measures include the *linear correlation coefficient* (also called the *product-moment correlation coefficient* or *Pearson's correlation coefficient*), and such non-parametric measures as *Spearman rank-order correlation coefficient* and *Kendall's tau*.

Cumulative Distribution Function:

Also referred to as the *distribution function, cumulative frequency function*, or the *cumulative probability function*. The cumulative distribution function expresses the probability the random variable assumes a value less than or equal to some value. A function to mathematically describe a random variable. Provides the cumulative probability of all outcomes of the random variable at or below a specific value.

Defense Medical surveillance:

An ongoing collection, analysis, and dissemination of uniform health information for monitoring the health of the DoD. The application of these data to a military medical surveillance system includes a functional capacity for data collection, analysis, and dissemination of information linked to public health programs.

Detection Limit: The lowest amount that can be distinguished from the normal background of an analytic instrument of method. The lowest

concentration that can be routinely quantified under specific limits of precision and accuracy.

Disease and Non-battle Injury:

A disease or injury to a person engaged in or supporting a military operation originating from other than the direct effects of weapons applied by the enemy force. DNBI includes heat/cold injury, accidents, and fratricide. DNBI does not include the effects of chemical, biological, or radiation weapons direct by an enemy force; direct enemy fire; or indirect weapons (e.g., land mines).

Environmental health surveillance:

The continuous process of assessing potential exposures and health effects, recommending risk reduction options, and evaluating risk reduction methods' effectiveness for chemicals of concern, pathogens, and radioactive materials in air, soil, and water. It includes coordination and information transfer with other responsible agencies or environmental management actions or preventive medicine programs.

Exposure: Contact of an organism with a chemical or physical agent. Exposure is quantified as the amount of an agent available at the exchange boundaries of the organism and is available for absorption.

Exposure Assessment:

The determination or estimation of the magnitude frequency, duration, and route or exposure. A process that integrates information on chemicals, environmental measurements, human behavior, and human physiology to estimate the exposure levels of doses of chemicals received by humans.

Exposure: The frequency and time personnel and equipment are subjected to a hazard.

Force Health Protection:

A unified strategy that protects service members from all health and environmental threats associated with military service. It is a "cradle-to-grave" continuum consisting of protection, monitoring, and management.

Goodness-of-fit-test: A statistical method to verify that the chosen distribution is consistent with the sample.

Hazard Quotient: The ratio of a single substance exposure level over a specified time period to a reference dose for that substance derived from a similar exposure period.

Hazards Index: The sum of more than one hazard quotient for multiple substances and/or multiple exposure pathways. The HI is calculated separately for chronic, subchronic, and short-term exposures.

Health Hazard: Any real or potential condition that can cause injury, illness, or death of personnel, damage to or loss of equipment, property or mission degradation.

Health Threat: Composite of all ongoing or potential enemy actions and environmental conditions that will reduce combat effectiveness through wounding, injuring, causing disease, and/or performance degradation.

Joint Force Operation:

A military operation involving more than one DoD component.

Komogorov-Smirnov:

A test of goodness-of-fit. Evaluates if a result in a sample may have reasonably come from a population with a theoretical distribution. Test assumes variable distribution is continuous.

Kruskal-Wallis Test: A nonparametric, rank-sum test, of the null hypothesis that x independent random samples came from the same populations.

Nonparametric alternative to ANOVA.

LC_{50}: Concentration that is lethal to 50% of the test animals.

Monte Carlo Analysis, Monte Carlo Simulation:

Monte Carlo Analysis is a computer-based method of analysis that uses statistical sampling techniques in obtaining a probabilistic approximation to the solution of a mathematical equation.

Operational Force: Department of Defense (DOD) military members, civilian personnel, civilian contractors, and personnel from non-DOD organizations directed by a Commander In Chief or other commander to accomplish an assigned mission.

Parameter: Parameter refers to the constants characterizing the probability density function or cumulative distribution function of a random variable. For example, the mean and standard deviation characterizing constants are called parameters.

Pharmacokinetics: The use of mathematical models for the quantitative study of the metabolic processes of absorption, distribution, biotransformation, and elimination of toxicants

Probability Density Function:

The PDF is also referred to as the *probability function* or the *frequency function*. For continuous random variables, that is, the random variables that can assume any value within some defined range (either finite or infinite), the probability density function expresses the probability that the random variable falls within some very small interval.

Probabilistic Model: A system whose output is a distribution of values.

Reference Dose: An estimate of an exposure level for the human population, including sensitive populations, that is likely to be without an appreciable risk of adverse health outcomes.

Sensitivity: The quantity of uncertainty in a forecast that is a result of both the uncertainty and model sensitivity of an assumption.

Sensitivity Analysis:

The computational procedure to determine the changes of the outcomes with changes in its parameters. If a small change in a parameter results in relatively large changes in the outcomes, the outcomes are "sensitive" to that parameter.

Triangular Distribution: A triangular shaped distribution used to represent phenomena that are not well characterized. When compared to a normal distribution, over estimates the portion of the distribution found in the tails.

Uncertainty: Represents a lack of knowledge about a input parameter or model.

Variability: Refers to the heterogeneity in an exposure parameter.

Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
CDF	Cumulative distribution function
CINC	Commander in Chief
CMMS	Comprehensive military medical surveillance
CONUS	Continental United States
DNBI	Disease and Non-battle Injury
DOD	Department of Defense
DODD	Department of Defense Directive
DODI	Department of Defense Instruction
EFH	Exposure Factors Handbook
EHS	Environmental Health Surveillance
HI	Hazard Index
IRIS	Integrated Risk Information System
LC_{50}	Lethal Concentration
LOAEL	Lowest Observable Adverse Effect Level
mg/kg:	Milligrams per kilogram
mg/l	Milligrams per liter
MOPP	Mission Oriented Protection Posture
MOS	Military Occupational Specialty
NOAEL	No Observable Adverse Effect Level
NRC	National Research Council
PDF	Probability density function

RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-based Concentrations
RfD_i	Inhalation Reference dose
RME	Reasonable Maximal Exposure
TEAM	Total Exposure Assessment Study
TWA	Threshold Limit Values
UF	Uncertainty factor
USEPA	United States Environmental Protection Agency

Appendix A: Metabolic Costs of Soldier's Common Tasks

METABOLIC COST OF MILITARY PHYSICAL TASKS								
VE, L/min		Vo_2,ml·kg^{-1}		%Vo_2max		Heart Rate		Task Description
Mean	SD	Mean	SE	Mean	SE	Mean	SE	
26.7	4.6	11.0	0.6	20.1	1.0	107.0	4.0	Maintain an M16A1 Rifle
13.7	1.1	4.9	0.2	8.9	0.3	87.0	3.0	Prolong Standing in a circulation control point
15.3	2.4	6.7	0.2	12.7	0.5	88.0	3.0	Lift 105mm Projectiles, Carry 25kg projectiles and lift
17.8	1.5	7.5	0.2	14.9	0.6	95.0	3.0	Relocate/establish operations, Lift 22.7 kg box
15.5	2.7	8.5	0.3	16.0	0.5	97.0	4.0	Lift 105mm Projectiles, Carry 25kg projectiles and lift
19.0	2.3	11.0	0.3	21.4	0.8	104.0	4.0	Rig a supply load on a modular platform for airdrop
17.3	2.0	6.7	0.2	12.2	0.4	87.0	2.0	Relocate/establish operations, Lower/lift 25kg box
18.8	3.1	9.5	0.1	17.9	0.6	100.0	4.0	Relocate/establish operation
19.6	2.1	9.1	0.3	18.0	0.8	98.0	4.0	Receive nonperishable subsistence; unload 40ft cont.
21.0	1.7	9.8	0.4	19.2	0.8	106.0	3.0	Relocate/establish operations: 22.7 kg box
24.5	1.6	9.6	0.4	17.7	0.5	98.0	1.0	Load crates of explosives onto truck 27.3kg crate
17.5	1.9	7.4	0.2	13.7	0.6	89.0	3.0	Perform emergency destruction operations
21.3	3.4	11.0	0.3	21.1	0.8	104.0	3.0	Load artillery pieces in preparation for firing
24.6	2.1	11.8	0.2	21.4	0.7	95.0	2.0	Move by foot wearing combat equipment no rucksack
26.8	2.0	12.2	0.4	23.9	0.7	101.0	1.0	Move by foot wearing combat equipment and 20kg ruck
20.3	5.0	12.0	0.2	21.9	0.9	103.0	6.0	Lift, carry, and move patients. 68 kg, 2-man litter team
34.0	4.7	17.4	0.6	33.5	1.1	130.0	5.0	load artillery pieces in preparation for firing. 45kg
21.8	6.7	14.0	0.4	26.8	1.1	115.0	5.0	load artillery pieces in preparation for firing. 45kg
25.9	3.0	14.4	0.4	28.4	1.1	107.0	2.0	Move by foot wearing combat equipment, no rucksack
32.1	2.0	13.9	0.4	27.3	0.7	110.0	3.0	Move by foot wearing combat equipment, 30gk sack
28.2	2.5	15.2	0.6	28.7	1.2	116.0	5.0	Move by foot with combat equipment, weapon & M-16
25.6	3.4	12.4	0.3	23.0	1.0	104.0	3.0	Lift 105mm Projectiles, 25kg and carry 15m
34.1	2.6	13.7	0.3	25.1	0.5	109.0	3.0	Unload & stack paper stock. 18.2 kg box
26.4	5.3	15.4	0.4	28.8	1.0	119.0	4.0	Relocate/establish operations. Lift 22.7 kg box
31.9	3.6	16.5	0.7	30.3	1.3	119.0	4.0	Relocate/establish operations. Lift 22.7 kg box
32.8	6.6	17.1	1.1	33.2	2.5	122.0	5.0	Dig individual defensive position

35.6	9.9	19.7	0.7	35.8	1.6	124.0	4.0	Employ hand grenades, engage a 5 m radius target
39.9	3.0	18.1	0.5	33.1	1.1	117.0	2.0	Move by foot with combat equipment and 20kg sack
61.7	6.9	30.3	0.7	59.2	2.7	162.0	6.0	Move under direct fire(rush and craw) with equipment
43.1	3.9	19.1	1.0	36.7	2.6	119.0	4.0	Move by foot with combat equipment and 20kg sack
39.9	5.6	23.2	0.4	43.5	1.0	126.0	4.0	Carry tow equipment, carry 24.5kg up a grade
50.2	4.7	21.1	1.0	40.8	2.0	126.0	5.0	Move by foot with combat equipment and 30kg sack
52.6	9.2	25.7	0.5	47.7	1.3	142.0	3.0	Move by foot with combat equipment and weapon
60.8	5.3	29.7	0.5	58.8	1.8	149.0	5.0	Move by foot with equipment and 20kg sack
104.8	22.9	41.4	1.1	76.2	1.8	167.0	3.0	Carry an M5 smoke pot with two 13.6 smoke pots
49.1	8.0	22.9	1.2	44.8	2.8	135.0	5.0	Lift 105 mm projectile, lift 25kg projectile
60.2	9.0	23.9	1.7	46.6	2.1	142.0	6.0	Lift, carry, and move patients. 81.8kg, 4-man litter team
44.2	7.5	24.6	1.1	46.8	2.4	137.0	6.0	Lift, carry, and move patients. 68.2kg, 4-man litter team
90.2	14.6	39.0	0.8	74.8	2.2	173.0	3.0	Carry tow equipment, carry 24.5kg up a grade
74.9	16.9	33.5	0.6	61.9	1.9	150.0	4.0	Move by foot with combat equipment no rucksack
52.5	8.4	27.0	1.8	51.8	3.9	146.0	8.0	Lift, carry, and move patients. 68 kg, 2-man litter team
68.7	8.1	29.5	1.0	58.4	1.3	153.0	3.0	Move over, through and around obstacles

Appendix B: Benzene Air Sampling Results

BENZENE AIR SAMPLING				
Camp	Laboratory Identification	Sample Identification	Benzene $\mu g/m^3$	Region
2	Z7755	GUA_TO1_7086_P	0.62	Tuzla Valley
2	E6094	GUA_TO1_7098_P	0.76	Tuzla Valley
2	E6261	GUA_TO1_7107_C	0.80	Tuzla Valley
2	E5995	GUA_TO1_7089_C	1.14	Tuzla Valley
2	E6265	GUA_TO1_7110_C	1.14	Tuzla Valley
2	E6264	GUA_TO1_7110_P	1.18	Tuzla Valley
2	X9575	NOR_011V_130	1.63	Tuzla Valley
2	E6259	GUA_TO1_7105_C	1.76	Tuzla Valley
2	Z7752	GUA_TO1_7084_P	1.80	Tuzla Valley
2	E6258	GUA_TO1_7105_P	1.84	Tuzla Valley
2	Z7756	GUA_TO1_7086_C	2.64	Tuzla Valley
2	X9576	NOR_010V_129	2.90	Tuzla Valley
2	Z7753	GUA_TO1_7084_C	2.93	Tuzla Valley
2	E6003	GUA_TO1_7092_P	3.08	Tuzla Valley
2	E6004	GUA_TO1_7092_C	3.30	Tuzla Valley
2	E6091	GUA_TO1_7101_P	5.34	Tuzla Valley
2	X9154	NOR_005V_126	5.43	Tuzla Valley
2	X9153	NOR_004V_121	5.98	Tuzla Valley
2	E6092	GUA_TO1_7101_C	6.42	Tuzla Valley
2	E5998	GUA_TO1_7095_C	10.52	Tuzla Valley
2	E5997	GUA_TO1_7095_P	12.91	Tuzla Valley
2	E6262	GUA_TO1_7107_P	0.25	Tuzla Valley
2	X8787	NOR_002V_119	0.25	Tuzla Valley
2	X8786	NOR_003V_120	0.25	Tuzla Valley
2	E5994	GUA_TO1_7089_P	0.25	Tuzla Valley
2	E6095	GUA_TO1_7098_C	0.25	Tuzla Valley
2	X8785	NOR_001V_118	0.25	Tuzla Valley
4	E5986	EAG_TO1_7097_C	0.79	Tuzla Valley
4	Z7758	EAG_TO1_7087_P	0.92	Tuzla Valley
4	E5985	EAG_TO1_7097_P	1.03	Tuzla Valley
4	E6103	EAG_TO1_7106_P	1.17	Tuzla Valley
4	Z7762	EAG_TO1_7088_C	1.35	Tuzla Valley
4	E6098	EAG_TO1_7100_C	1.39	Tuzla Valley
4	E6097	EAG_TO1_7100_P	1.42	Tuzla Valley
4	E6104	EAG_TO1_7106_C	1.45	Tuzla Valley
4	Y1177	EAG_TO1_175_P	1.52	Tuzla Valley
4	E6271	EAG_TO1_7112_C	1.69	Tuzla Valley
4	Z7761	EAG_TO1_7088_P	1.73	Tuzla Valley
4	Z7759	EAG_TO1_7087_C	1.73	Tuzla Valley
4	E6270	EAG_TO1_7112_P	1.75	Tuzla Valley

4	E5988	EAG_TO1_7090_P	1.75	Tuzla Valley
4	E5989	EAG_TO1_7090_C	2.05	Tuzla Valley
4	E5992	EAG_TO1_7094_C	2.13	Tuzla Valley
4	E6273	EAG_TO1_7114_P	2.13	Tuzla Valley
4	E6274	EAG_TO1_7114_C	2.22	Tuzla Valley
4	X5288	TZM_TO1_039_C	2.23	Tuzla Valley
4	E6100	EAG_TO1_7104_P	2.88	Tuzla Valley
4	E5991	EAG_TO1_7094_P	2.99	Tuzla Valley
4	E6101	EAG_TO1_7104_C	3.36	Tuzla Valley
4	X5290	TZM_TO1_039_P	3.63	Tuzla Valley
4	X5232	TZM_TO1_041_P	4.15	Tuzla Valley
4	X5292	TZM_TO1_040_P	4.60	Tuzla Valley
4	X5229	TZM_TO1_042_P	5.14	Tuzla Valley
4	X5233	TZM_TO1_041_C	5.51	Tuzla Valley
4	X5230	TZM_TO1_042_C	0.25	Tuzla Valley
4	Y1589	EAG_TO1_190_C	0.25	Tuzla Valley
4	Y1840	EAG_TO1_193_P	0.25	Tuzla Valley
4	Y1837	EAG_TO1_192_C	0.25	Tuzla Valley
4	Y1841	EAG_TO1_193_C	0.25	Tuzla Valley
4	Y1588	EAG_TO1_190_P	0.25	Tuzla Valley
11	Y1824	LUK_TO1_193_C	2.24	Tuzla Valley
11	X8790	LUK_001V_113	2.32	Tuzla Valley
11	Y1823	LUK_TO1_193_P	2.34	Tuzla Valley
11	X8800	LUK_009V_119	3.13	Tuzla Valley
11	X8795	LUK_010V_119	3.75	Tuzla Valley
11	X8794	LUK_005V_115	4.01	Tuzla Valley
11	X5591	LUK_TO1_046_C	4.12	Tuzla Valley
11	X9157	LUK_013V_122	4.19	Tuzla Valley
11	X5592	LUK_TO1_046_P	4.79	Tuzla Valley
11	X5286	LUK_TO1_045_P	4.98	Tuzla Valley
11	X8796	LUK_006V_117	5.56	Tuzla Valley
11	X8792	LUK_003V_115	6.35	Tuzla Valley
11	X5594	LUK_TO1_047_C	6.50	Tuzla Valley
11	X8798	LUK_011V_120	6.68	Tuzla Valley
11	X5588	SID_TO1_046_C	6.71	Tuzla Valley
11	X9156	LUK_014V_122	7.14	Tuzla Valley
11	X5595	LUK_TO1_047_P	8.50	Tuzla Valley
11	X5589	SID_TO1_046_P	9.36	Tuzla Valley
11	X5281	LUK_TO1_044_P	20.98	Tuzla Valley
11	X5283	LUK_TO1_044_C	23.20	Tuzla Valley
11	Y1042	LUK_TO1_171_C	0.25	Tuzla Valley
11	Y1821	LUK_TO1_192_C	0.25	Tuzla Valley
11	Y1274	LUK_TO1_174_P	0.25	Tuzla Valley
11	X5285	LUK_TO1_045_C	0.25	Tuzla Valley
14	X6571	ALI_001A_072	2.59	Tuzla Valley
15	X6570	ANG_001A_071	2.38	Tuzla Valley
1	E6846	DEM_TO1_7132_P	1.56	2nd Brigade

1	E6557	DEM_TO1_7122_C	1.79	2nd Brigade
1	E6845	DEM_TO1_7132_C	2.08	2nd Brigade
1	E6553	DEM_TO1_7119_P	2.18	2nd Brigade
1	E6554	DEM_TO1_7119_C	2.32	2nd Brigade
1	E6556	DEM_TO1_7122_P	2.43	2nd Brigade
1	E6842	DEM_TO1_7126_P	3.78	2nd Brigade
1	E6843	DEM_TO1_7126_C	4.90	2nd Brigade
1	E6849	DEM_TO1_7129_C	0.25	2nd Brigade
1	E6848	DEM_TO1_7129_P	0.25	2nd Brigade
9	Y1049	LIN_TO1_168_C	1.56	2nd Brigade
9	Y1048	LIN_TO1_168_P	2.36	2nd Brigade
9	Y1563	LIN_TO1_183_C	2.45	2nd Brigade
9	Y1171	LIN_TO1_171_P	0.25	2nd Brigade
9	Y2330	LIN_TO1_193_C	0.25	2nd Brigade
9	Y2327	LIN_TO1_192_C	0.25	2nd Brigade
9	Y2329	LIN_TO1_193_P	0.25	2nd Brigade
9	Y2333	LIN_TO1_194_C	0.25	2nd Brigade
9	Y2332	LIN_TO1_194_P	0.25	2nd Brigade
9	Y2326	LIN_TO1_192_P	0.25	2nd Brigade
9	Y1172	LIN_TO1_171_C	0.25	2nd Brigade
9	Y1795	LIN_TO1_191_C	0.25	2nd Brigade
10	X6569	LIS_001A_066	2.93	2nd Brigade
10	Y1556	LIS_TO1_183_P	0.25	2nd Brigade
10	Y1259	LIS_TO1_174_C	0.25	2nd Brigade
10	Y1169	LIS_TO1_171_C	0.25	2nd Brigade
10	Y1018	LIS_TO1_168_P	0.25	2nd Brigade
10	Y2354	LIS_TO1_194_C	0.25	2nd Brigade
10	Y2348	LIS_TO1_192_C	0.25	2nd Brigade
10	Y1557	LIS_TO1_183_C	0.25	2nd Brigade
10	Y2357	LIS_TO1_195_C	0.25	2nd Brigade
10	Y2353	LIS_TO1_194_P	0.25	2nd Brigade
11	Y1582	LUK_TO1_189_P	1.67	2nd Brigade
3	E6134	SAR_TO1_7102_C	1.41	Sarajevo
3	E6133	SAR_TO1_7102_P	1.49	Sarajevo
3	E6127	SAR_TO1_7097_P	2.41	Sarajevo
3	E6128	SAR_TO1_7097_C	2.48	Sarajevo
3	Z8514	SAR_TO1_7085_C	2.96	Sarajevo
3	J0142	SAR_TO1_7111_P	3.22	Sarajevo
3	E6131	SAR_TO1_7099_C	3.28	Sarajevo
3	J0143	SAR_TO1_7111_C	3.34	Sarajevo
3	Z8513	SAR_TO1_7085_P	3.38	Sarajevo
3	E6130	SAR_TO1_7099_P	3.39	Sarajevo
3	Z8517	SAR_TO1_7088_C	3.51	Sarajevo
3	Z8516	SAR_TO1_7088_P	3.98	Sarajevo
3	J0140	SAR_TO1_7105_C	4.18	Sarajevo
3	J0146	SAR_TO1_7112_C	4.29	Sarajevo
3	J0139	SAR_TO1_7105_P	4.41	Sarajevo

3	Z8519	SAR_TO1_7091_P	5.48	Sarajevo
3	Z8520	SAR_TO1_7091_C	5.59	Sarajevo
3	J0145	SAR_TO1_7112_P	6.19	Sarajevo
3	E6125	SAR_TO1_7094_C	10.44	Sarajevo
3	E6124	SAR_TO1_7094_P	10.97	Sarajevo
5	E6827	UGL_TO1_7125_P	0.94	Ugljevic
5	E6834	UGL_TO1_7131_C	0.98	Ugljevic
5	E6548	UGL_TO1_7121_C	1.06	Ugljevic
5	E6547	UGL_TO1_7121_P	1.24	Ugljevic
5	E6833	UGL_TO1_7131_P	1.44	Ugljevic
5	E6551	UGL_TO1_7122_C	1.61	Ugljevic
5	E6550	UGL_TO1_7122_P	1.93	Ugljevic
5	E6828	UGL_TO1_7125_C	0.25	Ugljevic
7	Y1032	GEN_TO1_169_P	1.38	1st Brigade
7	Y1302	GEN_TO1_181_C	2.85	1st Brigade
7	Y1800	GEN_TO1_189_P	0.25	1st Brigade
7	Y1250	GEN_TO1_175_C	0.25	1st Brigade
7	Y1249	GEN_TO1_175_P	0.25	1st Brigade
8	Y2338	KIM_TO1_197_P	1.19	1st Brigade
8	Y1038	KIM_TO1_172_P	1.42	1st Brigade
8	Y1256	KIM_TO1_177_C	1.52	1st Brigade
8	Y1299	KIM_TO1_182_C	1.64	1st Brigade
8	Y1039	KIM_TO1_172_C	1.72	1st Brigade
8	Y2339	KIM_TO1_197_C	1.92	1st Brigade
8	Y1014	KIM_TO1_169_P	7.79	1st Brigade
8	Y1015	KIM_TO1_169_C	12.27	1st Brigade
8	Y2336	KIM_TO1_193_C	0.25	1st Brigade
8	Y1255	KIM_TO1_177_P	0.25	1st Brigade
8	Y2345	KIM_TO1_196_C	0.25	1st Brigade
8	Y1298	KIM_TO1_182_P	0.25	1st Brigade
12	E6089	MCG_TO1_7097_C	0.55	1st Brigade
12	E6250	MCG_TO1_7110_C	0.78	1st Brigade
12	E6000	MCG_TO1_7086_P	0.78	1st Brigade
12	E6255	MCG_TO1_7114_P	0.82	1st Brigade
12	E6243	MCG_TO1_7104_P	0.85	1st Brigade
12	E6256	MCG_TO1_7114_C	0.99	1st Brigade
12	E6247	MCG_TO1_7107_C	1.17	1st Brigade
12	E6244	MCG_TO1_7104_C	1.29	1st Brigade
12	E6085	MCG_TO1_7100_P	1.31	1st Brigade
12	E6246	MCG_TO1_7107_P	1.34	1st Brigade
12	E6253	MCG_TO1_7111_C	1.34	1st Brigade
12	E6001	MCG_TO1_7086_C	1.41	1st Brigade
12	E6106	MCG_TO1_7093_P	1.46	1st Brigade
12	E6107	MCG_TO1_7093_C	1.52	1st Brigade
12	E6252	MCG_TO1_7111_P	1.69	1st Brigade
12	Y1574	MCG_TO1_186_P	8.86	1st Brigade
12	Y1575	MCG_TO1_186_C	9.41	1st Brigade

12	Y1296	MCG_TO1_179_C	10.72	1st Brigade
12	Y1380	MCG_TO1_176	16.78	1st Brigade
12	Y2587	MCG_TO1_193_P	20.08	1st Brigade
12	Y2588	MCG_TO1_193_C	23.13	1st Brigade
12	Y1295	MCG_TO1_179_P	26.02	1st Brigade
12	Y1572	MCG_TO1_182_C	34.43	1st Brigade
12	Y2324	MCG_TO1_191_C	86.89	1st Brigade
12	Y2323	MCG_TO1_191_P	106.19	1st Brigade
12	Y1037	MCG_TO1_170_P	0.25	1st Brigade
12	Y1165	MCG_TO1_172_P	0.25	1st Brigade
12	E6088	MCG_TO1_7097_P	0.25	1st Brigade
12	Y1166	MCG_TO1_172_C	0.25	1st Brigade
12	Y1571	MCG_TO1_182_P	0.25	1st Brigade
12	Y1035	MCG_TO1_170_C	0.25	1st Brigade
13	Y1253	GER_TO1_179_C	1.49	Germany
13	Y1229	GER_TO1_176_P	0.25	Germany
13	Y2431	GER_TO1_204_P	0.25	Germany
13	Y2432	GER_TO1_204_C	0.25	Germany
13	Y2672	GER_TO1_212_P	0.25	Germany
13	Y2673	GER_TO1_212_C	0.25	Germany
13	Y0971	GER_TO1_169_C	0.25	Germany
13	Y0970	GER_TO1_169_P	0.25	Germany
16	Y1244	KAP_TO1_180_P	2.17	Hungary
16	Y1243	KAP_TO1_180_C	2.75	Hungary
16	Y1155	KAP_TO1_173_P	2.85	Hungary

Appendix C: Volatile Organic Compound Sampling Procedures

Introduction:

- A modified EPA Toxic Organic TO-1 Ambient Air Monitoring Method using Supelco Carbosieve 300 sampling tubes is used to measure volatile organic compounds (VOCs) in ambient air. These sampling tubes can efficiently collect compounds from vinyl chloride to naphthalene.
- Each tube is spiked before and after the sampling episode by the laboratory to ensure quality control/quality assurance (QA/QC). The total volume collected should range from between 18-20 liters and should not exceed the 20 liters. For general VOC sampling, **19 liters** is desired.
- Each sampling episode consists of using the following equipment.
    - Three sampling tubes:
        - Primary
        - Collocated
        - Field blank
    - Two sampling pumps.
    - Pump calibrator
- Each tube has a black arrow on it that indicates the direction of airflow through the tube. On some tubes, this arrow is hard to distinguish because of the darkening from the repeated heating needed for desorption and conditioning. If there is no arrow on the tube, do not use the tube and return the tube unused. Always attach the pump tubing to the end that the arrow is pointing. The adsorbent is packed in the tube in a way to allow for maximum efficiency when sampled in the direction that the arrow is pointing.
- When you are handling the tubes do so by holding the middle of the tube. Do not hold by the ends. The oils from your fingers on the ends of the tube could be desorbed with the sample causing contamination problems. Keep the tubes refrigerated before and after sampling. Do not allow tubes to get wet! Ship sampling tubes in cooler with ice and ensure they are sealed in zip lock bags to prevent water contamination.
- Each stainless steel sample tube is contained in a shipping container, ensure the appropriate container is labeled with the appropriate sample information. If

information contained on the shipping container is incorrect the sample will be considered invalid and the sampling site must be re-sampled.

Pump Calibration: [pump calibration should be conducted before and after each sampling episode].

- Record the following on the Field Data Sheet
  - ***Calibration Location***
  - ***Calibrator Id***
  - ***Calibration Operator***
  - ***Calibration Date***
  - ***Pump ID***
- Connect the calibration sampling tube (an extra tube dedicated to calibration) to pump tubing with arrow pointing toward pump (Figure 1).
- Connect other end of sample calibration tube to the calibrator (Gilibrator or Buck). If using a Gilibrator use the 1-250 ml cell.
- Insure sufficient level of bubble solution in calibrator to allow the plunger to be submerged.
- Turn the pump on and depress and release the black button on the calibrator and observe pump flow.
- Turn the fine adjustment, located on the pump intake, to achieve desired flow rate (37-

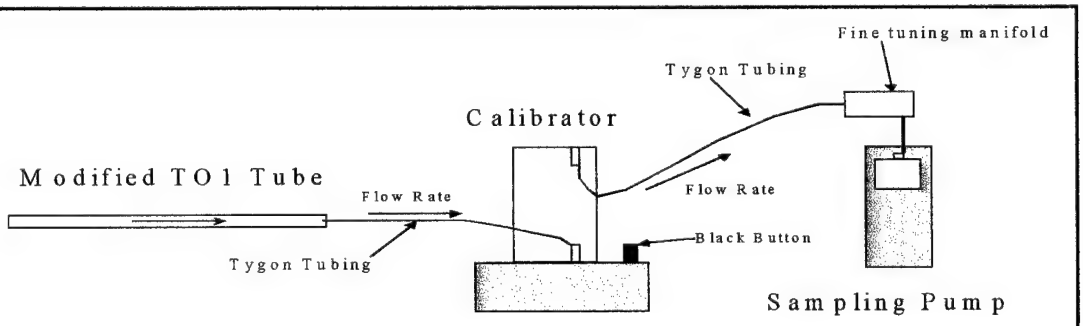


Figure 1. Modified TO1 Calibration Setup

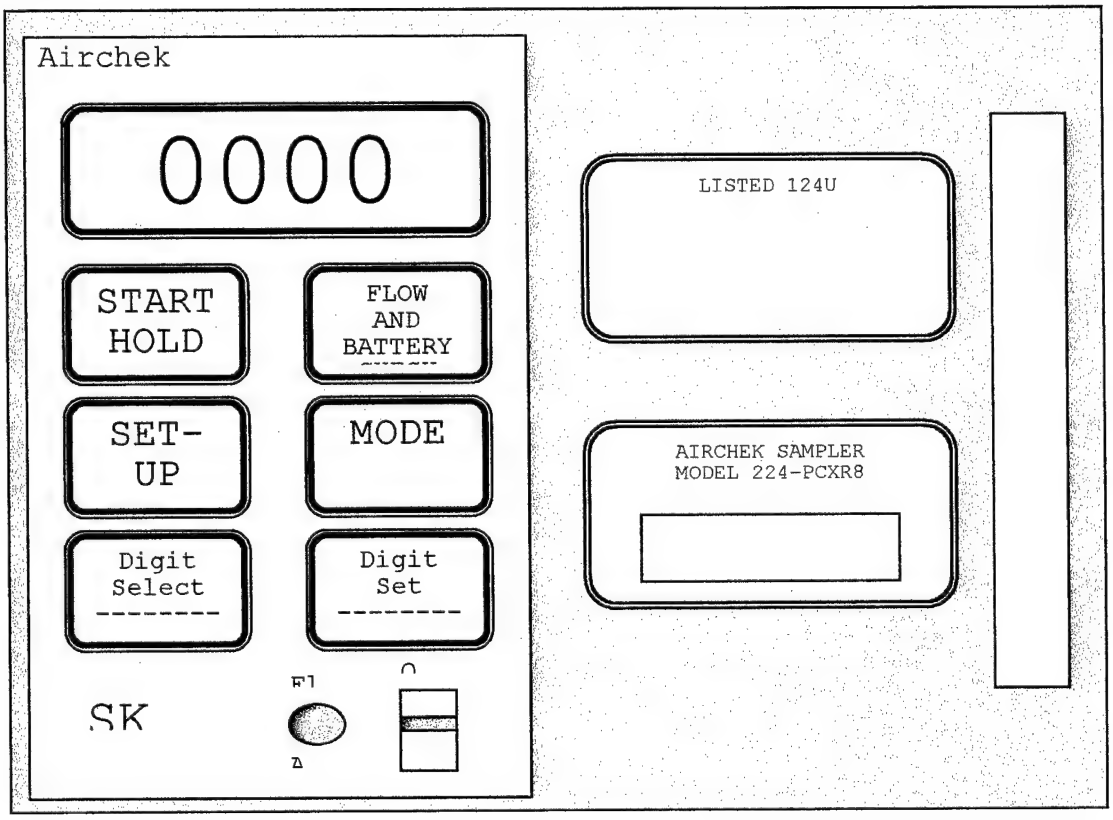
41mL/min.). [A flow rate of 39.5 ml/min will yield a sample volume of 19 liters over an 8-hour sampling period].

- Take 3-5 readings from the calibrator and record average flow on field data sheet (*Flow Rate Pre*).
- Pre and post sampling calibrations should be conducted. However the post calibration

should just record the final flow rate, no adjustment of the flow is necessary (i.e. hook the sampler to the calibrator [Gilibrator or Buck] and take the average of 3-5 readings)

Programming the Pump (if applicable) see Figure 2 for SKC controls:

- Turn pump on and press START/HOLD
- Press SET UP
- Press MODE
  - Set DELAY START using the digit select and digit set buttons (e.g. 20 min.)
- Press MODE
  - Set SAMPLE PERIOD, using the digit select and digit set buttons (i.e. 480 min.)
- Press MODE
  - Set PUMP PERIOD, using the digit select and digit set buttons (i.e. 480 min.)
- Press ????



SKC Sampling Pump Control Pad

Battery Recycling/Recharging:

- Only charge a totally discharged battery (use a batter discharger if available).
- Charge battery for a minimum of 12 hrs.
- Use only a fully charged battery for sampling (fully charged batteries will last for approximately 10 hrs.).
-

Sample Collection and Recovery:

- SAMPLE COLLECTION
  - Take the following equipment to the sampling site after pump calibration.
    - Two pumps
    - Three sampling tubes and containers
      - Primary sample
      - Collocated sample
      - Field blank
    - Tygon or Teflon tubing
    - Thermometer/barometer
    - GPS

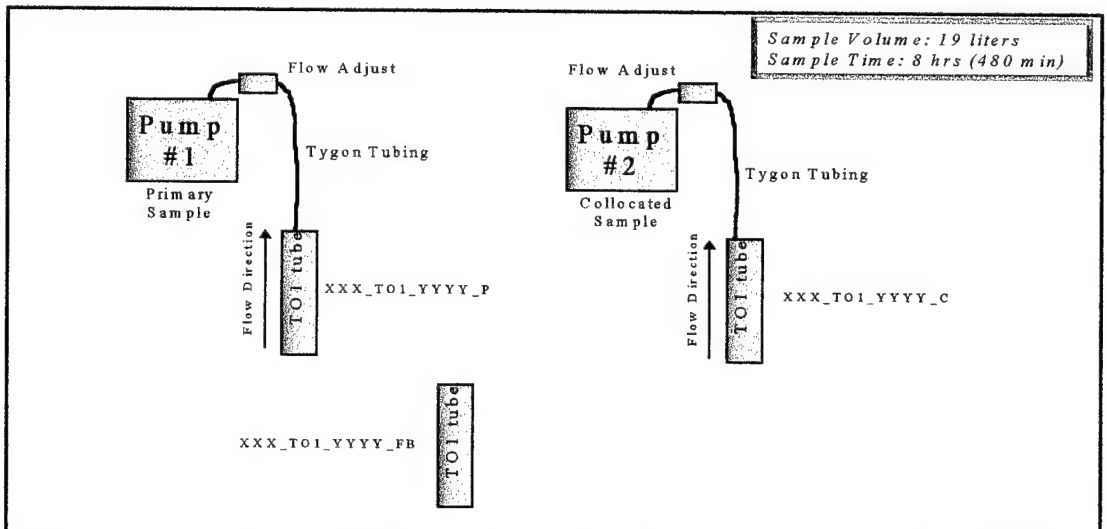
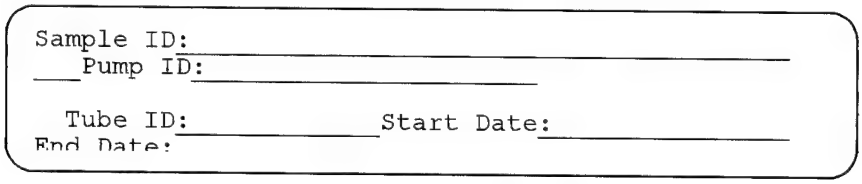


Figure 3. Location XXX Modified TO1 Sample Setup for Jday YYYY

  - Insert sample tubes into Tygon tubing (see Figure 3) and ensure arrow on tube points toward pump.

- Record the following information on the sample label.
  - ***Sample ID***
  - ***Pump ID***
  - ***Start Date***
  - *Tube ID (if present on tube)*

  Label Example (actual size):



- Record the following data on field data sheet.
  - ***Sample ID***
  - ***Sample Location***
  - ***Field Blank ID***
  - *Sample Type (S-Sample, FB-Field Blank, TB-Trip Blank)*
  - *Tube ID*
  - ***Operator***
  - *VOC Method (e.g. TO1, DAAMS)*
  - ***Latitude Degrees***
  - ***Latitude Minutes***

Longitude Degrees

  - ***Longitude Minutes***
  - ***Start Date***
  - ***Start Time***
- Place pump in zip-lock bag if raining and note in the "*Rain*?" field on the field data sheet.
- Handle field blank in identical fashion as sample tubes and return it to its shipping container. Apply label to field blank container and note field blank ID.

- SAMPLE RECOVERY

- At end of sampling period, bring field blank to the sampling site and handle in identical fashion to the samples.
- Remove sampling tubes from pump ensuring the correct tube is returned to its appropriate storage container.
- Record the following information on the sample label.
  - ***End Date***
- Record the following data on field data sheet.
  - ***End Date***
  - ***End Time***
  - ***Sample Time* - (minutes) from sampling pump**
  - *Field Notes*

- POST SAMPLING
  - Retrieve sampling tubes and pumps and return to work area.
  - Store sample tubes in refrigerator or cooler.
  - Conduct post-sampling calibration on sampling pumps. Assemble calibration setup and record the average of 3-5 readings from calibration (Note: Do not adjust any controls, just record final flow rate). Record flow rate in the "*Flow Rate Post*" field on the field datasheet. If battery is dead and you are unable to obtain final flow reading, note on field data sheet.

Appendix D: Gas Chromatography/Mass Spectrometry Procedures

STANDING OPERATING PROCEDURE
ANALYTICAL SPECTROMETRY DIVISION

ANALYSIS OF VOLATILE ORGANICS BY GAS CHROMATOGRAPHY/MASS SPECTROMETRY
U.S. ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE
ANALYTICAL SPECTROMETRY DIVISION
BUILDING E2100
ABERDEEN PROVING GROUND, MARYLAND 21010-5422

MCHB-DC-LAS FEBRUARY 1997
STANDING OPERATING PROCEDURE NUMBER 47.1

ANALYSIS OF VOLATILE ORGANICS BY THERMAL DESORPTION/GAS CHROMATOGRAPHY/
MASS SPECTROMETRY - MODIFIED METHOD TO1

1.0 PURPOSE

This standard operating procedure (SOP) describes the procedures used at USACHPPM/DLS/ASD/GC-MS for the determination of volatile organics by Environmental Protection Agency (EPA) Modified Method TO1, modified by use of Carbotrap 300 Thermal Desorption Tubes. Modified Method TO1 is a thermal desorption/purge-and-trap/gas chromatographic/mass spectrometric (TD/P&T/GC/MS) procedure used to detect and quantify the compounds listed.

VOLATILE ORGANICS ANALYSIS DATA SHEET – METHOD

REPORTING LIMITS (MRL)

ANALYTE:	CAS #(a)	MRL (b)
Benzene	71-43-2	10
Bromobenzene	108-86-1	10
Bromochloromethane	74-97-5	10
Bromodichloromethane	75-27-4	10
Bromoform	75-25-2	10
Bromomethane	74-83-9	10
n-Butylbenzene	104-51-8	10
sec-Butylbenzene	135-98-8	10
tert-Butylbenzene	98-06-6	10
Carbon tetrachloride	56-23-5	10
Chlorobenzene	108-90-7	10
Chloroethane	75-00-3	10
Chloroform	67-66-3	10
Chloromethane	74-87-3	10
2-Chlorotoluene	95-49-8	10
4-Chlorotoluene	106-43-4	10
Dibromochloromethane	124-48-1	10
1,2-Dibromo-3-chloropropane	96-12-8	10
1,2-Dibromoethane	106-93-4	10

ANALYTE:	CAS #(a)	MRL (b)
Dibromomethane	74-95-3	10
1,2-Dichlorobenzene	95-50-1	10
1,3-Dichlorobenzene	541-73-1	10
1,4-Dichlorobenzene	106-46-7	10
Dichlorodifluoromethane	75-71-8	10
1,1-Dichloroethane	75-34-3	10
1,2-Dichloroethane	107-06-2	10
1,1-Dichloroethene	75-35-4	10
cis-1,2-Dichloroethene	156-59-2	10
trans-1,2-Dichloroethene	156-60-5	10
1,2-Dichloropropane	78-87-5	10
1,3-Dichloropropane	142-28-9	10
2,2-Dichloropropane	590-20-7	10
1,1-Dichloropropene	563-58-6	10
cis-1,3-Dichloropropene	10061-01-5	10
trans-1,3-Dichloropropene	10061-02-6	10
Ethylbenzene	100-41-4	10
Hexachlorobutadiene	87-68-3	10
Isopropylbenzene	98-82-8	10
4-Isopropyltoluene	99-87-6	10
Methylene chloride	75-09-2	10
Naphthalene	91-20-3	10

ANALYTE:	CAS #(a)	MRL (b)
n-Propylbenzene	103-65-1	10
Styrene	100-42-5	10
1,1,1,2-Tetrachloroethane	630-20-6	10
1,1,2,2-Tetrachloroethane	79-34-5	10
Tetrachloroethene	127-18-4	10
Toluene	108-88-3	10
1,2,3-Trichlorobenzene	87-61-6	10
1,2,4-Trichlorobenzene	120-82-1	10
1,1,1-Trichloroethane	71-55-6	10
1,1,2-Trichloroethane	79-00-5	10
Trichloroethene	79-01-6	10
Trichlorofluoromethane	75-69-4	10\
1,2,3-Trichloropropane	96-18-4	10
1,2,4-Trimethylbenzene	95-63-6	10
1,3,5-Trimethylbenzene	108-67-8	10
Vinyl chloride	75-01-4	10
o-Xylene	95-47-6	10
m-Xylene	108-38-3	10
p-Xylene	106-42-3	10
Methylcyclopentane	96-37-7	10
Hexane	110-54-3	10
n-decane	124-18-5	10

ANALYTE:	CAS #(a)	MRL (b)
Cyclopentane	287-92-3	10
Cyclohexane	110-82-7	10
Isooctane	111-65-9	10
Methanol	67-56-1	10

(a) Chemical Abstract Services Registry Number.

(b) Method Reporting Limit (nanograms (ng) per tube) based on lowest standard analyzed.

2.0 SCOPE

2.1 Volatile compounds in ambient air are collected onto thermal desorption tubes. The thermal desorption tubes are analyzed by a thermal desorption, purge-and-trap method. An inert gas is purged through a heated thermal desorption tube. Purged sample components are bubbled through a water column, then trapped in a focusing tube containing suitable sorbent materials. When purging is complete, the sorbent trap is heated and backflushed with helium to desorb trapped sample components. The analytes are desorbed directly to a large bore capillary column that is temperature programmed to separate the analytes which are then qualified and quantified with a mass spectrometer (MS).

2.2 Qualitative identifications are confirmed by analyzing standards under the same conditions used for samples and comparing resultant mass spectra and GC retention times. Each identified component is quantitated by relating the MS response for an appropriate selected ion produced by that compound to the MS response for another ion

produced by an internal standard.

2.3 SENSITIVITY - EPA Method Modified TO1 requires a yearly determination of method detection limits using the formula MDL = S*t(n-1,1-alpha=0.99) where:s=the standard deviation of the mean analyte recovery and t(n-1,1-alpha = .99)= the Student's t value for the 99% confidence level with n-1 degrees of freedom limit.

2.4 LINEARITY - The limited dynamic range of the mass spectrometer combined with the wide range of response factors, an order of magnitude for some compounds, severely limits the linearity of the method. Currently, the standard calibration curve runs from 10 ng to 500 ng per tube.

2.5 PRECISION AND ACCURACY - The method requires a one-time demonstration of the operator's ability to generate acceptable data. A MDL determination is required.

3.0 DEFINITIONS

3.1 The internal standards (ISTD) are pure analytes added to a sample, extract, or standard solution in known amounts and used to measure the relative responses of the

method analytes and surrogates that are components of the same sample or solution. The internal standards must be analytes that are not sample components. Internal standards are added to all standards, blanks, and samples prior to analysis.

3.2 The surrogate standards (SURR) are unique compounds which are extremely unlikely to be found in any sample, and which are added to a sample aliquot in known amounts and measured with the same procedures used to measure other sample components. The purpose of the surrogate standards is to monitor method performance with each sample. Surrogates are vapor-spiked onto all sample tubes after conditioning and prior to collection.

3.3 Co-located Samples. Two separate samples collected at the same time and place under identical circumstances and treated exactly the same throughout field and laboratory procedures. Analyses of co-located samples give a measure of the precision associated with sample collection, preservation, and storage, as well as laboratory procedures.

3.4 Laboratory Blank. A thermal desorption tube or other blank matrix that is treated exactly as a sample including exposure to all glassware, equipment, solvents, internal standards, and surrogates that are used with other samples. The laboratory blank is used to determine if method analytes or other interferences are present in the laboratory environment, or the apparatus.

3.5 Field Blank. A thermal desorption tube that is placed in a sample container in the laboratory and treated as a sample in all respects, including shipment to the sampling site, exposure to the sampling site conditions, storage, preservation, and all analytical procedures. The purpose of the trip blank is to determine if method analytes or other interferences are present in the field environment.

3.6 Sample Matrix Spike.(MS) A separate thermal desorption tube to which known quantities of method analytes are added in the laboratory. The Matrix Spike is then collected and analyzed exactly like a sample; its purpose is to show the collection efficiency of the compounds of interest in a field setting. The background concentrations of the analytes in the sample matrix must be determined in a separate aliquot.

3.7 Calibration Standard (CAL). A thermal desorption tube spiked with the analytes in the volatile standards mixes. The standard is used to calibrate the instrument response with respect to analyte concentration.

3.8 Calibration Check Standard (CHK). A thermal desorption tube spiked with the analytes in the volatile standards mixes. The calibration check standard is used to check the instrument response with respect to calibration standards.

4.0 DISCUSSION

Volatile organic compounds and surrogates with low water solubility are thermally extracted (purged) from the sample matrix by bubbling an inert gas through the thermal

desorption tube. Purged sample components are trapped in a focusing tube containing suitable sorbent materials. When purging is complete, the sorbent tube is heated and backflushed with helium to desorb the trapped sample components into a capillary gas chromatography (GC) column interfaced to a mass spectrometer (MS). The GC oven is temperature programmed to facilitate the separation of the method analytes which are then detected with the MS. Compounds eluting from the GC column are identified by comparing their measured mass spectra and retention times to reference spectra and retention times in a data base. Reference spectra and retention times for analytes are obtained by the measurement of calibration standards under the same conditions used for samples. The concentration of each identified component is measured by relating the MS response of the quantitation ion produced by that compound to the MS response of the quantitation ion produced by a compound that is used as an internal standard. Surrogate analytes, whose concentrations are known in every sample, are measured with the same internal standard calibration procedure.

5.0 RESPONSIBILITIES

Sample analysis will be performed by analysts experienced in thermal desorption/ purge and trap/ GC/MS analysis or under the direct supervision of experienced senior personnel - this SOP assumes that the analyst is familiar with Tekmar Thermal Desorption and Purge and Trap equipment, Hewlett-Packard (HP) GC model 5890, MSD model 5970B or equivalent, and MS-DOS Chemstation/Enviroquant software. It is the analyst's responsibility to read and understand this SOP and EPA Method TO1 (EPA TO-17 when approved). Method detection

limits will be determined on a yearly basis by the laboratory. Precision and accuracy demonstration will be performed on a one-time basis by each analyst. Technical data review will be performed on all data packages by experienced, senior-level personnel.

6.0 REQUIREMENTS

6.1 EQUIPMENT

6.1.1 Tekmar LSC 2000 (or Tekmar 3000) Purge and Trap Unit, or equivalent.

6.1.2 Tekmar 6016 Thermal Desorption Autosampler, or equivalent.

6.1.3 Hewlett-Packard 5890 Gas Chromatograph with a jet separator and a HP 5970B Mass Selective Detector, or equivalent (GC should have subambient capabilities).

6.1.4 Hewlett Packard DOS Chemstation (G1034C, Version C.02.00) with Enviroquant Forms software (G1032C, Version C.00.02), or the equivalent.

6.1.5 Tekmar Thermotrap Tube Conditioner for 1/4" X 7" thermal desorption tubes, 12 position; or equivalent.

6.2 CONSUMABLES

6.2.1 Syringes. 10 µL to 500 µL.

6.2.2 Volumetric Flasks. 10 mL - 100 mL, Class A with ground glass stopper.

6.2.3 Disposable Pipettes and bulbs.

6.2.4 Mininert reaction vials with two-way valve caps.

6.2.5 Capillary Column. J & W 75 m x 0.53 mm ID, 3 □m phase DB-624 cat. #125-1374, or equivalent.

6.2.6 Vocarb 3000 trap/Purge Trap K (Supelco Cat# 2-1066) for the Tekmar LSC 2000, or the Vocarb 3000 trap/Purge Trap K(Supelco Cat# 2-4920) for the Tekmar 3000 Concentrator, or equivalent.

6.2.7 Thermal Desorption Tubes, Supelco Carbotrap 300, 7" X 1/4" Stainless Steel Cat# 2-0370, or equivalent.

6.2.8 Supelco M1 1/4" Ferrules Cat# 2-2087, or equivalent.

6.2.9 Supelco Thermal Desorption Tube Containers (TDS3) 1/4" X 7", Cat# 2-5065.

6.3 REAGENTS AND CHEMICALS

6.3.1 Methanol, Purge and trap grade.

6.3.2 The following Volatile Organic Mixes are available from these commercial vendors: Supelco, Ultra Scientific, PE Express, and AccuStandard.

6.3.3 The tuning solution, 4-bromofluorobenzene (BFB), can be bought at the working concentration, 25 ug/mL in methanol; otherwise, it must be volumetrically diluted to this concentration.

6.3.4 The internal standard solution (ISTD), is composed of Pentafluorobenzene, 1,4-Difluorobenzene, Chlorobenzene-d5, and 1,4-Dichlorobenzene-d4. It is purchased at a stock concentration of 20,000 ug/mL and volumetrically diluted to a working concentration of 50 ng/uL (25 uL of the 20,000 ug/mL stock ISTD solution into 10 mLs P & T grade Methanol). One microliter is vapor-spiked onto all samples,

blanks, and standards immediately prior to analysis.

6.3.5 The surrogate solution (SURR) is composed of Toluene-D8, Bromofluorobenzene, Benzene-D6, and Dibromofluoromethane. It is purchased at a stock concentration of 20,000 ug/mL (without Benzene-D6). The Benzene-D6 needs to be purchased at a stock concentration of 20,000 ug/mL or it can be prepared by volumetrically diluting 115uL of neat Benzene'D6 (density = 0.879 g/mL) to 5 mLs of P & T Methanol which yields a 20,000 ug/mL stock concentration. The working level SURR solution is prepared by volumetrically diluting 25 uL of the two stocks (each 20,000 ug/mL) into 10 mLs P & T grade Methanol to yield a working level concentration of 50 ng/uL. One microliter is vapor-spiked onto all samples prior to sample collection. The stock surrogate analyte solutions are also added to the actual calibration standards at concentrations equal to that of the analytes.

6.3.6 Analyte mixes (hydrocarbons and liquids) should be purchased at a stock concentration level - 2000 ug/mL in methanol, in order facilitate combination and serial dilution. All standard mixes are stored in clean mininert vials in the volatiles freezer. Standard mixes are replaced bi-monthly. This is the current standard dilution scheme:

6.3.6.1 Stock Analyte Mix: Concentration = 500 ng/uL in methanol.

1000 uL of Volatiles Liquids at 2000 ug/mL

1000 uL of Hydrocarbons Mix at 2000 ug/mL

100 uL of Custom Surrogate Mix at 20,000 ug/mL

100 uL of Benzene-d6 at 20,000 ug/mL

1800 uL of Purge and Trap Methanol

4000 uL or 4 mL of a 500 ng/uL Analyte Mix

6.3.6.2 Serial Dilutions to yield the Calibration Standard Range, 250, 100, 50, 25, 10 ng/uL.

250 ng/uL - 500 uL of Stock Analyte Mix at 500 ng/uL plus 500 uL of purge and trap methanol.

100 ng/uL - 200 uL of Stock Analyte Mix at 500 ng/uL plus 800 uL of purge and trap methanol.

50 ng/uL - 100 uL of Stock Analyte Mix at 500 ng/uL plus 900 uL of purge and trap methanol.

25 ng/uL - 50 uL of Stock Analyte Mix at 500 ng/uL plus 950 uL of purge and trap methanol.

10 ng/uL - 20 uL of Stock Analyte Mix at 500 ng/uL plus 980 uL of purge and trap methanol.

These standards are used for calibration purposes. If possible, two Lots or vendors should be represented. Standards are vapor-spiked onto conditioned tubes - 1 uL of analyte standard and 1 uL of the ISTD mix.

7.0 PROCEDURES

7.1 LABORATORY PREPARATION

7.1.1 Check gas cylinders (liquid nitrogen, compressed nitrogen, and helium). If less than 300 psi, change cylinders.

7.1.2 Step the Tekmar LSC 2000 to bake. Make sure that a thermal desorption tube is in the position indicated. Make sure that the proper method is loaded into the LSC 2000 - Method 4 is currently in use.

7.1.3 Check the standards to make sure none are expired. See dates on mininert vials. The Liquids expire after two months; the BFB Tuning Mix expires after two months; and the Internal Standard and Surrogate Solution expires after six months. If the standards have expired: open the vial, transfer the contents into the waste methanol bottle, rinse the vial and stop cock with clean methanol. Allow to air dry. Place glass vial into GC oven for 10 min. at 150° C. Allow to cool. Replace the standard using a fresh ampule. Label the mininert vial and record all pertinent information in the standards log book (see Section 10.1). Put standards back in the freezer.

7.1.4 Take the thermal desorption tubes off the Tekmar 6016. These must be reconditioned prior to reuse. (See USACHPPM SOP No. 48.1).

7.1.5 Set up area for analysis - insure that adequate workspace exists to process samples in an orderly manner.

7.1.6 Get the samples out of the sample refrigerator, and allow to come to room temperature.. Check LISMD # and Field # against the chain of custody (COC) form. If there is no COC form, then check against the buckslip.

7.1.7 All Carbotrap 300 tubes must be vapor-spiked with 1 uL of the Internal Standard Mix prior to analysis.

7.2 DAILY ANALYSIS

7.2.1 Enter the Manual Tune Menu under MSTune in ENVTOP. Under the Tune menu, Perform a Standard Autotune. Run air & water check within Diagnostics. Annotate the maintenance log book and save the hardcopies of the autotune and the air & water check in the Autotune book. If the autotune fails or looks different from previous autotune- see VOC team leader for possible corrective action.

7.2.2 Write a sample run sequence with Chemstation using the correct numbering for data files and then save. See section 10.7 for guidance on numbering data files.

7.2.3 Prepare the Tune Check (BFB), the Calibration Check Standard (CHK), the Laboratory Fortified Blank (LFB), and a Laboratory Reagent Blank (LRB). BFB is prepared by spiking 1 uL of the 25 ng/uL BFB standard onto a conditioned tube using the spiking apparatus. The CHK is prepared by spiking 1 uL of the 50 ng standard mix and 1 uL of the ISTD mix onto a conditioned tube using the spiking apparatus. The LFB is prepared by spiking 1 uL of the 25 ng standard mix and 1 uL of the ISTD mix onto a conditioned tube using the spiking apparatus. The LRB is prepared by spiking a conditioned tube with 1 uL of both the SURR and ISTD mix using the spiking apparatus.

7.2.4 Change ALS sequence on the Tekmar LSC 2000.

7.2.5 Place the tube spiked with BFB on the Tekmar 6016 in position 1 using new M1 ferrules. Tighten all fittings. Use LOAD AND RUN SEQUENCE from SEQUENCE in ENVTOP and START on the Tekmar 2000, after entering the sample number in the autosequence field. If the tune passes (see BFB tune criteria in Section 8.1) using TUNER in data analysis window, record in the log books (record the area of mass 95, the file name, the retention time and scan that passed) and save spectra to forms from

the TUNER menu (tune.csv). If the tune fails - the analyst must reinject the tune until it passes the criteria. If the tune continues to fail - see VOC team leader for corrective action.

7.2.6 Set up the CHK and LRB in positions 2 and 3 on the Tekmar 6016 using new M1 ferrules. Tighten all fittings. Start the desorption on the check standard (press START on the LSC 2000 after changing the autosequence positions to 2 to 3) and start the sequence run (use *position and run* under *sequence* on the PC. Do not use *load and run sequence* because you will overwrite the tune you just ran and you will have to start over).

7.2.7 As soon as the check standard is done acquiring, perform the continuing calibration check using the *Concal* menu after quantitation. Save the calibration check standard to forms from the *Concal* menu (calib.csv) Make adjustments to the calibration file using *Easy ID* if necessary. Ideally all analytes should be quantitated correctly by the software, as manual integrations should be kept to a minimum.

Modified TO1 requirements:

The 50 ng CHK STD should have RSD < 30% for all Compounds. It is acceptable to proceed if 5 or fewer compounds have %RSD's greater than 30%.

The LRB should be free of all target analytes. Currently we B-qualify these compounds when present in the reagent blank.

This criteria must be met before analysis can proceed!

Additionally, there should not be significant sensitivity changes from previously run standards or the calibration curve. There should not be significant response factor deviations (%RSD's) for all other target compounds.

If the check standard fails to meet the above criteria, it must be reanalyzed. See VOC team leader for corrective action if there are any problems meeting these requirements.

7.2.8 When the check standard and laboratory blank pass, start loading the samples onto the autosampler in proper sequence using new M1 ferrules for each and tightening all fittings.

7.2.9 Sample Analysis: After loading the samples, which were spiked with the ISTD mix, change the sequence on the LSC 2000 to reflect the positions used. When all is ready, start the sequence. Remember to be very careful since the samples cannot be reanalyzed.

7.2.10 After the samples are analyzed, check each for the following:

7.2.10.1 Internal Standard Area Counts: Compare to the daily check standard. The area counts cannot be above twice the area counts in the check standard or below half the area counts in the check standard. If a sample fails, then it must be qualified.

7.2.10.2 Surrogate recoveries must be within accepted QC limits. If a sample fails, then the report narrative must be annotated as such.

7.2.10.3 Large unknown peaks in the chromatogram should be

library searched and a report should be attached to the quantitation report.

7.2.11 Record all pertinent information in the instrument sample log book.

7.3 DATA MANIPULATION

7.3.1 After data is collected and initially quantitated on the acquiring instrument, it is transferred to the network under the instrument directory where it was acquired (use File Manager). From here it can be accessed at any GC/MS PC.

7.3.2 Full quant reports are then generated, reporting spectra for actual hits. The analyst must check the quant reports for bad hits, line through bad hits on the quant reports, then have the reports double-checked by senior-level experienced personnel before deleting bad hits. After bad hits are deleted, the analyst must make forms files (quant.csv) for all samples (DOLIST "QT 0,0,`C"").

7.3.3 The analyst must then prepare sample headers from the *Envmain* program under the *MS Chemstation* window. For guidance on forms generation, see the appropriate Enviroquant manual.

7.4 CURVE GENERATION

There must be an initial calibration curve comprised of at least 5 concentration levels. Each standard level must contain all analytes of concern, including surrogates and internal standards. Calculate the average response factor (RF) and relative standard deviation (RSD).

If the RSD of any analyte or surrogate mean RF exceeds 30%, either analyze additional standard aliquots to obtain acceptable results, or take action to improve GC/MS performance.

A new standard calibration curve must be generated when the %RSD's are >30% in the daily check standard and reanalysis does not take care of the problem. A six-point curve is analyzed at representative concentrations: 10, 25, 50, 100, 250, and 500 ng/tube.

7.5 VAPOR SPIKING OF STANDARD SOLUTIONS

7.5.1 All standard solutions will be vapor-spiked onto the thermal desorption tubes in one microliter aliquots. All samples conditioned for field collection will be spiked with one microliter of a 50 ng/uL surrogate solution prior to sample collection.

7.6 INSTRUMENT SETPOINTS

7.6.1 Purge and Trap Equipment: Tekmar LSC 2000 with ALS 6016

7.6.1.1 Temperature Zones

-Lines and Valves - 110C

-Trap Desorb Preheat - 240C

-Trap Desorb - 250C

-Trap Bake - 260C

7.6.1.2 Time Settings

-Sample Desorb - 8 min.

-Dry Purge - 3 min.

-Desorb - 2.5 min.

-Bake - 11 min.

7.6.1.3 Flow Rates (Helium)

-Sample Desorb Flow - 40 mL/min.

-Trap Desorb Flow - ~15 mL/min.

7.6.2 Gas Chromatograph Setpoints

-Jet Separator (Det. A) - 200C

-Transfer Line (Det. B) - 210C

-Oven - 35□C for 5 min., then 7C/min. to 198□C

7.6.3 Mass Selective Detector Setpoints

-Solvent Delay - 2 min.

-Mass Range - 35-300

-Threshold - varies

-Scans/sec - 1.3

-Source Temperature - ~200C

7.7 WASTE AND HAZARDOUS MATERIALS.

7.7.1 Methanol wastes are generated during the conduct of this procedure and must be disposed of in accordance with USACHPPM Hazardous Materials Management Plan, Division SOPs, and APG Reg 200-1.

7.8 INTERFERENCES

7.8.1 Impurities in the purge gas and/or contamination of the analytical system. The analytical system must be demonstrated to be free from contamination under the conditions of analysis by analyzing laboratory reagent blanks.

7.8.2 During storage and analysis great care should be exercised to keep any volatile organic compounds (e.g. methylene chloride, freon) away from the samples. Volatile air samples are stored in a refrigerator in the VOA lab. Great care must be taken to make sure that the VOA lab is kept as solvent-free as possible -- this includes keeping traffic to a minimum in this laboratory, especially when sample analysis is taking place.

7.9 SAMPLE COLLECTION, PRESERVATION, AND STORAGE

7.9.1 Sample collection, preservation, and storage prior to laboratory receipt is the responsibility of field personnel and Laboratory Operations Improvement Program.

7.9.2 Samples received by the GC/MS Volatiles Team will be refrigerated at 4□C (±2C) in an organic-free environment until analysis. There are separate water/air and soil sample refrigerators in the Volatile's Analysis Laboratory for sample storage. Samples should be analyzed as soon as possible after receipt, and should be analyzed within 14 days of collection.

7.10 General Maintenance

7.10.1 General good housekeeping should be practiced in the GC/MS

area.

7.10.2 Septa should be replaced at a minimum of once a month.

7.10.3 Trap should be replaced at least once every quarter or sooner if problems arise.

7.10.4 Mass spectrometer source must be cleaned if BFB tune cannot be achieved (that is after all other courses of action have been tried, retuning and reinjection of BFB).

7.10.5 Rough pump oil should be changed every 6-12 months.

8.0 QUALITY CONTROL

8.1 The mass selective detector is tuned to pass BFB criteria. This criteria must be met at the beginning of each 12 hour analysis window. Sample analysis is accomplished using the same MSD settings as were used to analyze BFB.

BFB TUNING CRITERIA

Mass	Relative Abundance
50	15 - 40 percent of Mass 95
75	30 - 80 percent of Mass 95
95	100 Base Peak
96	5 - 9 percent of Mass 95
173	<2 percent of Mass 174
174	>50 percent of Mass 95

175	5 - 9 percent of Mass 175
176	>95 percent but <101 percent of Mass 174
177	5 - 9 percent of Mass 176

8.2 All analytes in the standard calibration curve should have a %RSD less than 30%. All analytes in the daily check standard (50 ng) should have a %RSD less than 30%. It is allowable that up to 5 analytes can have a %RSD greater than 30%.

8.3 A laboratory reagent blank must be analyzed each day prior to sample analysis. It should be free of analyte contamination. Field blanks will accompany each sample set.

8.4 Analysts will generate a one-time Demonstration of Capability by running an MDL determination. Method MDL's will be generated yearly.

8.5 Matrix Spikes (MS) will be collected and analyzed wherever practical, depending upon the field situation.

8.6 Surrogate recoveries should fall within the QC limits as described in Section 10.6. Samples with recoveries outside the QC limits will be qualified. The explanation and impact statement are included in the case narrative attached to each data package.

8.7 The internal standard area counts of each sample should fall within the QC limits of +100% and -50% of the integrated area counts of the internal standards from the daily check standard. Samples failing this criteria will be qualified as such in the case narrative.

8.8 Independently prepared check standards should be analyzed at least quarterly.

8.9 Documentation of all quality control should be easily accessible upon request and review.

9.0 CALCULATIONS

9.1 All calculations are based on the internal standard method for target compounds.

9.2 Quantitation is achieved through the QUANT program using the initial calibration curve as the reference. The method file is updated as needed (rerunning of a curve).

9.3 For detections of non-target compounds the following equation is used to estimate the quantity.

$$\frac{\text{AREA} * {}^{1}\text{AMT}}{{}^{1}\text{AREA}} = \text{AMT}$$

AREA = area counts of unknown

AMT = estimated amount of unknown

^{1}AREA = area counts of closest uninterfered internal standard

[1]AMT = amount of closest uninterfered internal standard

10.0 RECORDKEEPING

10.1 All standards shall be recorded in the VOC Standard logbook when opened for use in analysis. The following information shall be recorded: calendar date, vendor name, description, catalog number, lot number, concentration, solvent, date expired, analyst initials. The same information shall be attached to the mininert vial that holds the standard. Colored tape is also used to color-code volatile standards and their respective syringes. Any standard dilutions made shall also be recorded in this book; record the aliquot of stock standard used, the total volume made, the solvent used, and the final concentration of the dilution.

10.2 All samples shall be logged into the VOC log book when received by team personnel. They will then be stored in the appropriate refrigerator in the VOA lab.

10.3 When analyzed, all relevant sample information will be entered into the appropriate (instrument-specific) Sample Run Log notebook. Information recorded for each sample should include: LISMD #, Field #, DOS file #, collection date, injection time, volume collected, and ALS position. The analyst shall also record the date of analysis, the analyst's name, the project which is being analyzed, the name of the sequence, and the analytical method. The analyst shall sign the bottom of the page and date when complete, and must also line out unused portions of the page. The technical data reviewer shall also sign the bottom of the page and date during the data review process.

10.4 All maintenance, repairs and performance checks shall be documented in the instrument's Maintenance Log Book. Daily autotune and verification of BFB tunes shall be maintained in loose-leaf notebooks at the instrument.

10.5 Hard copies of data packages will be kept in the laboratory for at least 1 year.

10.6 Surrogate recoveries must be documented/monitored and the QC limits re-evaluated at least annually. The QC limits are set at $\pm$ 3SD around the calculated mean recovery for each surrogate. There should not be dramatic changes from previous limits.

10.7 A file naming convention is used to identify the data. The first letter signifies the type of data that was acquired such as;

T tune

C calibration standard

K calibration check standard

B blank

S sample

M matrix spike

The second character designates which instrument was used (1, 2, or 3).

The third character lists the sample type whether soil or water or air (S W A).

The fourth identifies the method, 1 for Modified TO1 and 5 for 524 for example.

The fifth number keys to the month, 1 for January and A for October etc.

The remaining 3 digits specify the chronological order of samples analyzed in the month.

10.8 New standards received by the lab are logged into the standard notebook and any accompanying certification papers stored in the Certification Notebook.

11.0 SAFETY CONSIDERATIONS

11.1 The toxicity or carcinogenicity of chemicals used in this method have not been precisely defined. The following analytes have been identified as known or suspected human or mammalian carcinogens: Benzene, carbon tetrachloride, 1,4-dichlorobenzene, 1,2-dichloroethane, hexachlorobutadiene, 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, chloroform, 1,2-dibromoethane, tetrachloroethane, trichloroethane and vinyl chloride. Minimize exposure to concentrated analytical standards.

11.2 Minimize exposure to methanol which is present in all vendor standard solutions.

12.0 REFERENCES

12.1 Determination of Volatile Organic Compounds in Ambient Air Using Tenax Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS), Revision 1.0, April 1984, Methods for the Determination of Toxic Organic Compounds in Air, 1990.

12.2 Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS), Capillary Column Technique; EPA SW-846 Module, Method #8260A Revision 1, September 1994. .

12.3 The Preparation , Revision, Control, and Archiving of Standing Operating Procedures; SOP No. DLS 4.0, U.S. Army Environmental Hygiene Agency, Directorate of Laboratory Sciences, May 1993.

Appendix E: Equilibration of Soldier's Ventilatory Rates

Task Description	Ve m^3/hr	CARB (m^3/hr)	Shamoo/ Linn (m^3/hr)
Prolong Standing in a circulation control point	0.82	Light (<1.4)	1.1
Lift 105mm Projectiles, Carry 25kg projectiles & lift	0.92		
Lift 105mm Projectiles, Carry 25kg projectiles & lift	0.93		
Relocate/establish operations, Lower/lift 25kg box	1.04		
Perform emergency destruction operations	1.05		
Relocate/establish operations, Lift 22.7 kg box	1.07		
Relocate/establish operation	1.13		
Rig a supply load on a modular platform for airdrop	1.14		
Receive nonperishable subsistence; unload 40ft cont.	1.18		
Lift, carry, & move patients. 68 kg, 2-man litter team	1.22		
Relocate/establish operations: 22.7 kg box	1.26		
Load artillery pieces in preparation for firing	1.28		
load artillery pieces in preparation for firing. 45kg	1.31	Medium (1.4-2.6)	
Load crates of explosives onto truck 27.3kg crate	1.47		
Move by foot, combat equipment no rucksack	1.47		Medium (1.5)
Lift 105mm Projectiles, 25kg and carry 15m	1.54		
Move by foot, combat equipment, no rucksack	1.56		
Relocate/establish operations. Lift 22.7 kg box	1.59		
Maintain an M16A1 Rifle	1.6		
Move by foot, combat equipment and 20kg ruck	1.61		
Move by foot, combat equipment, weapon & M-16	1.69		
Relocate/establish operations. Lift 22.7 kg box	1.92	Moderate (1.8)	
Move by foot wearing combat equipment, 30gk sack	1.93		
Dig individual defensive position	1.97		
load artillery pieces in preparation for firing. 45kg	2.04		
Unload & stack paper stock. 18.2 kg box	2.05		
Employ hand grenades, engage a 5 m radius target	2.13		Heavy (2.3)
Move by foot with combat equipment and 20kg sack	2.39		
Carry tow equipment, carry 24.5kg up a grade	2.39		
Move by foot with combat equipment and 20kg sack	2.58	Heavy (2.6 – 3.8)	
Lift, carry & move patients. 68.2kg, 4-man litter team	2.65		
Lift 105 mm projectile, lift 25kg projectile	2.95		
Move by foot with combat equipment and 30kg sack	3.01		
Lift, carry, & move patients. 68 kg, 2-man litter team	3.15		
Move by foot with combat equipment and weapon	3.15		
Lift, carry & move patients. 81.8kg, 4-man litter team	3.61		
Move by foot with equipment and 20kg sack	3.65		
Move under direct fire(rush & craw) with equipment	3.7	Very Heavy (>3.8)	
Move over, through and around obstacles	4.12		
Move by foot with combat equipment no rucksack	4.5		
Carry tow equipment, carry 24.5kg up a grade	5.41		
Carry an M5 smoke pot with two 13.6 smoke pots	6.29		

Appendix F: Military Occupational Skills Physical Demand Ratings

Military Occupational Skills Physical Demand Ratings		
Enlisted		
Military Occupational Specialty (MOS)	Career Management Field (CMF)	Physical Demand Rating
00	Special Duty Assignment	light
02	97 - Band	Light
09	Commissioned Officer Candidate	Light
11	11 - Infantry	Very Heavy
12	12 - Combat Engineer	Very Heavy
13	13 - Field Artillery	Very Heavy
14	14 - Air Defense Artillery	Very Heavy
16	14 - Air Defense Artillery	Very Heavy
18	18 - Special Forces	Very Heavy
19	19 - Armor	Very Heavy
24	23 - Missile Defense Systems	Medium
25	25 - Signal Corps	Moderately Heavy
27	35 - Electronic Maintenance/Calibration	Very Heavy
31	31 - Signals Operations	Moderately Heavy
33	33 - Electronic Warfare/Intercept	Medium
35	35 - Electronic Maintenance/Calibration	Moderately Heavy
37	37 - Psychological Operations	Medium
39	35 - Electronic Maintenance/Calibration	Heavy
42	71 - Administration	Light
43	92 - Supply and Servicing	Very Heavy
44	63 - Mechanical Maintenance	Very Heavy
45	63 - Mechanical Maintenance	Very Heavy
46	46 - Public Affairs	Light
51	51 - General Engineering	Very Heavy
52	63 - Mechanical Maintenance	Very Heavy
54	54 - General Science (Chemical)	Very Heavy
55	55 - Ammunition	Very Heavy
57	92 - Supply and Service	Very Heavy
62	63 - Mechanical Maintenance	Very Heavy
63	63 - Mechanical Maintenance	Very Heavy
67	67 - Aircraft Maintenance	Heavy/Very Heavy
68	67 - Aircraft Maintenance	Heavy/Very Heavy
71	71 - Administration	Light/Medium
73	71 - Administration	Light
74	31 - Signal Corps	Moderately heavy/heavy
75	77 - Petroleum and Water	Light- Medium
76	91 - Medical	Medium
77	77 - Petroleum and Water	Very Heavy
79	79 - Recruitment	Light
81	81 - Topographic Engineer	Medium
82	13 - Field Artillery	Very Heavy

83	81 - Topographic Engineering	Moderately Heavy
88	88 - Transportation	Very Heavy
91	91 - Medical	Moderately heavy
92	92 - Supply and Service	Heavy - Very Heavy
93	93 - Aviation Operations	Very Heavy
95	95 - Military Police	Moderately Heavy
96	96 - Military Intelligence	Medium
97	96 - Military Intelligence	Medium
98	98 - Signals Intel/Elect War	Moderately Heavy

OFFICERS

Military Occupational Specialties (MOS)	Career Management Field (CMF)	Physical Demand Rating
00	Non-operational Status	Light
11	11 - Infantry	Very Heavy
12	12 - Armor	Very Heavy
13	13 -Field Artillery	Very Heavy
14	14 - Air Defense	Very Heavy
15	93 - Aviation Operations - pilots	Medium
18	18 - Special Forces	Very Heavy
21	21 - Corps of Engineers	Heavy
25	25 - Visual Information	Light
31	95 - Military Police	Moderately Heavy
35	96 - Military Intelligence	Light
39	37 - Psychological Operations	Light
42	71 - Administration	Light
44	44 - Finance	Light
46	Public Affairs	Light
55	71 - Administration	Light
56	71 - Administration	Light
60	91 - Medical	Light
61	91 - Medical	Light
62	62 - Medical	Light
63	63 - Dental	Light
64	91 - Medical	Light
65	91 - Medical	Light
66	91 - Medical	Light
67	91 - Medical	Light
70	91 - Medical	Light
73	91 - Medical	Light
74	54 - General Science (Chemical)	Medium
88	88 - Transportation	Light
90	55 - Ammunition	Light
91	91 - Medical	Moderately heavy
92	92 - Supply and Service	Heavy

Appendix G: Soldiers Body Weight Analysis

Average Weight of Active Duty Soldiers from 1990-1996*		
Year	Number of active duty Soldiers with HRA	Average weight
1990	3829	167.56
1991	78825	167.74
1992	104906	168.94
1993	76524	169.18
1994	38258	168.82
1995	67887	169.69
1996	53724	169.57
Total (1990-1996)	423953	168.93
* Average weights are estimates take from available Health Risk Appraisal (HRA) data.		

MOMENTS				QUANTILES(DEF=5)			
N	423953	Sum Wgts	423953	100% Max	470	99%	235
Mean	168.9369	Sum	71621322	75% Q3	185	95%	213
Std Dev	26.79813	Variance	718.1396	50% Med	170	90%	202
Skewness	0.067561	Kurtosis	0.655087	25% Q1	150	10%	135
				0% Min	50	5%	125
Mode	160	Range	420			1%	105

Histogram	#	Boxplot
470+*	1	*
.*	3	*
.*	3	*
.*	1	*
.*	1	*
.*	1	*
330+*	4	*
.*	30	*
.*	129	0
.*	468	0
.*	2431	0
.*****	11372	0
.***************	38503	|
190+************************************	97349	+-----+
.**	129241	*--+--*
.*********************************	91360	+-----+
.***************	40280	|
.*****	11565	|
.*	704	0
.*	347	0
50+*	160	0

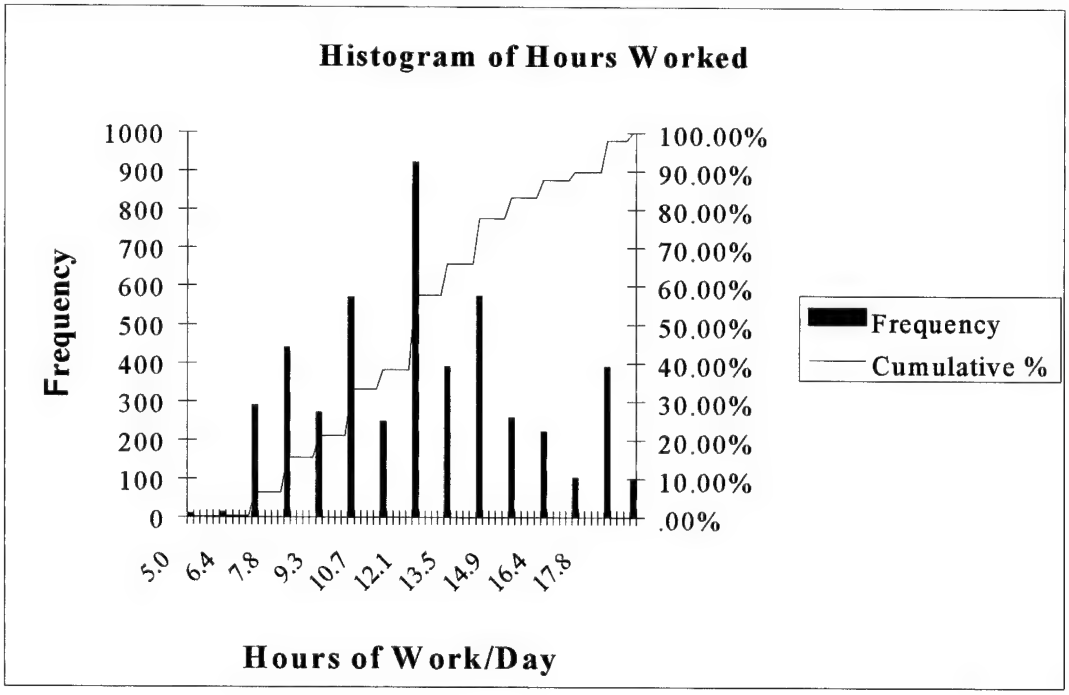
----+----+----+----+----+----+----+----+----+---

* may represent up to 2693 counts*

Appendix H: Deployment Time Activity

Bosnia Deployment Summary Statistics - Hours Slept By Career Management Field												
	Mean	Median	Mode	Standard Deviation	Sample Variance	Kurtosis	Skewness	Range	Min	Max	Count	95% Confidence
Total	5.9	6	6	1.14	1.24	3.00	-0.26	13	2	15	4683	5.86 - 5.93
No MOS	6.41	6	6	1.97	3.88	6.53	1.99	11	4	15	56	5.88 - 6.94
Air Defense	5.69	7	7	1.14	1.31	3.19	-0.14	2	6	8	216	6.87 - 7.05
Armor	5.84	6	6	1.11	1.24	3.44	-0.34	6	2	8	160	5.67 - 6.02
Aviators	6.08	6	6	1.02	1.05	3.49	-0.39	6	2	8	225	5.92 - 6.20
Field Artillery	6.24	6	6	1.15	1.32	2.45	-0.19	7	3	10	394	6.14 - 6.37
Maintenance	5.79	6	6	1.22	1.50	3.17	-0.33	6	2	8	122	5.53 - 6.00
Medical	6.10	6	6	1.16	1.34	3.35	-0.37	6	2	8	162	5.88 - 6.26
Military Intel	5.98	6	6	1.07	1.16	2.96	-0.18	6	2	8	284	5.38 - 6.10
Military Police	5.87	6	6	1.07	1.15	2.84	-0.17	6	2	8	460	5.70 - 5.92
Signal	5.89	6	6	1.27	1.62	2.90	-0.35	6	2	8	258	5.72 - 6.04
Logistics	5.85	6	6	1.17	1.37	3.11	0.37	6	2	8	830	5.76 - 5.92
Transportation	6.15	6	6	1.20	1.44	2.38	-0.18	4	4	8	33	5.66 - 6.52
Infantry	5.83	6	6	1.14	1.32	2.67	-0.09	6	2	8	362	5.64 - 5.91
Administration	5.87	6	6	1.29	1.65	4.83	0.17	13	2	15	380	5.78 - 5.97
Engineers	5.87	6	6	1.11	1.22	2.94	-0.36	6	2	8	832	5.78 - 5.93

Bosnia Deployment Summary Statistics - Hours Worked By Career Management Field												
				Standard	Sample							95%
	Mean	Median	Mode	Deviation	Variance	Kurtosis	Skewness	Range	Min	Max	Count	Confidence
Total	12.25	12	12	3.21	10.33	2.32	0.24	12	7	19	4760	12.22 - 12.40
No MOS	11.22	12	12	3.01	9.07	-0.35	0.40	11	7	18	59	10.44 - 12.01
Air Defense	13.46	14	12	2.63	6.94	3.10	-0.35	12	7	19	219	13.15 - 13.86
Armor	11.17	10	12	3.15	9.94	2.62	0.72	11	7	18	164	10.67 - 11.64
Aviators	12.01	12	12	2.90	8.42	2.50	0.11	12	7	19	227	11.63 - 12.39
Field Artillery	11.06	11	7	3.49	12.25	2.14	0.49	12	7	19	407	10.87 - 11.55
Maintenance	10.93	10	8	3.19	10.15	-0.07	0.85	11	7	18	122	10.36 - 11.50
Medical	13.94	13	12	3.35	11.23	1.59	0.34	11	8	19	162	13.40 - 14.44
Military Intel	12.32	12	12	2.74	7.55	2.64	0.11	12	7	19	287	12.00 - 12.64
Military Police	13.56	14	14	2.63	6.90	3.22	-0.25	12	7	19	467	13.35 - 13.82
Signal	12.31	12	12	3.16	10.00	2.44	0.44	12	7	19	262	11.92 - 12.69
Logistics	12.32	12	12	2.95	8.71	2.63	0.34	12	7	19	831	12.18 - 12.58
Transportation	11.14	11	8	3.05	9.32	2.45	0.53	11	7	18	36	10.04 - 12.07
Infantry	11.54	12	12	3.40	11.57	2.19	0.32	11	7	18	362	11.58 - 12.28
Administration	12.5	12	12	2.76	7.65	2.59	0.10	13	6	19	380	12.80 - 13.25
Engineers	12.10	12	10	3.55	12.67	2.10	0.44	12	7	19	832	11.88 - 12.47



TOTAL SAMPLE

WORK:

Skewness/Kurtosis tests for Normality: TOTAL SAMLPE HOURS of WORK				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.000	0.000	.	0.0000

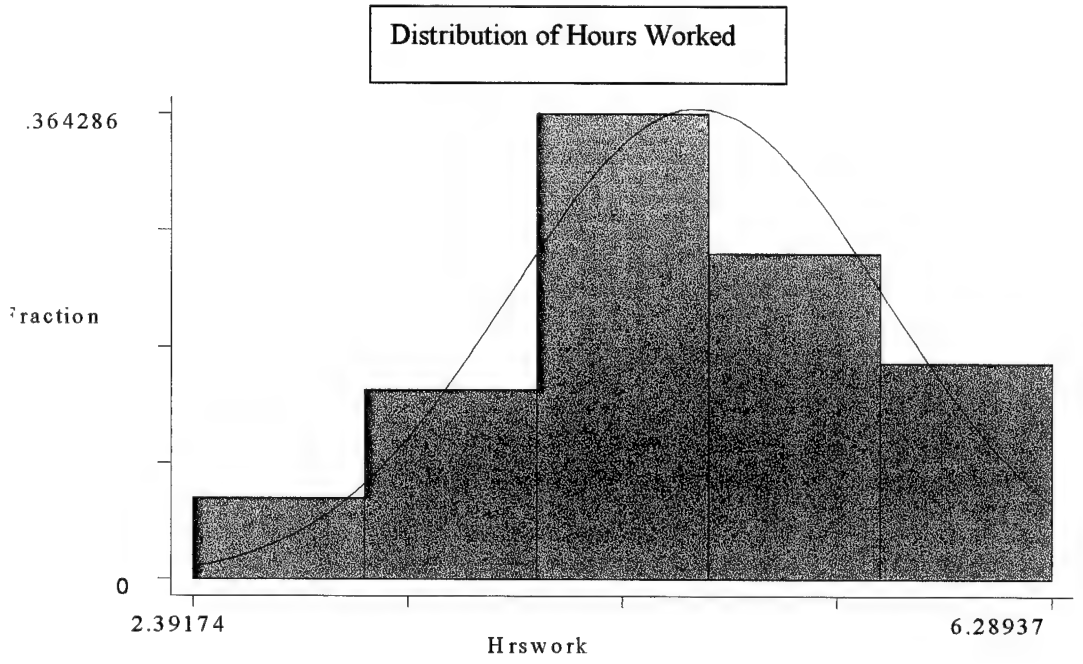
Shapiro-Francia W' test for normal data: TOTAL SAMLPE HOURS of WORK					
Variable	Obs	W'	V'	z	Pr>z
Hrswork	4760	0.98455	18.136	3.582	0.00017

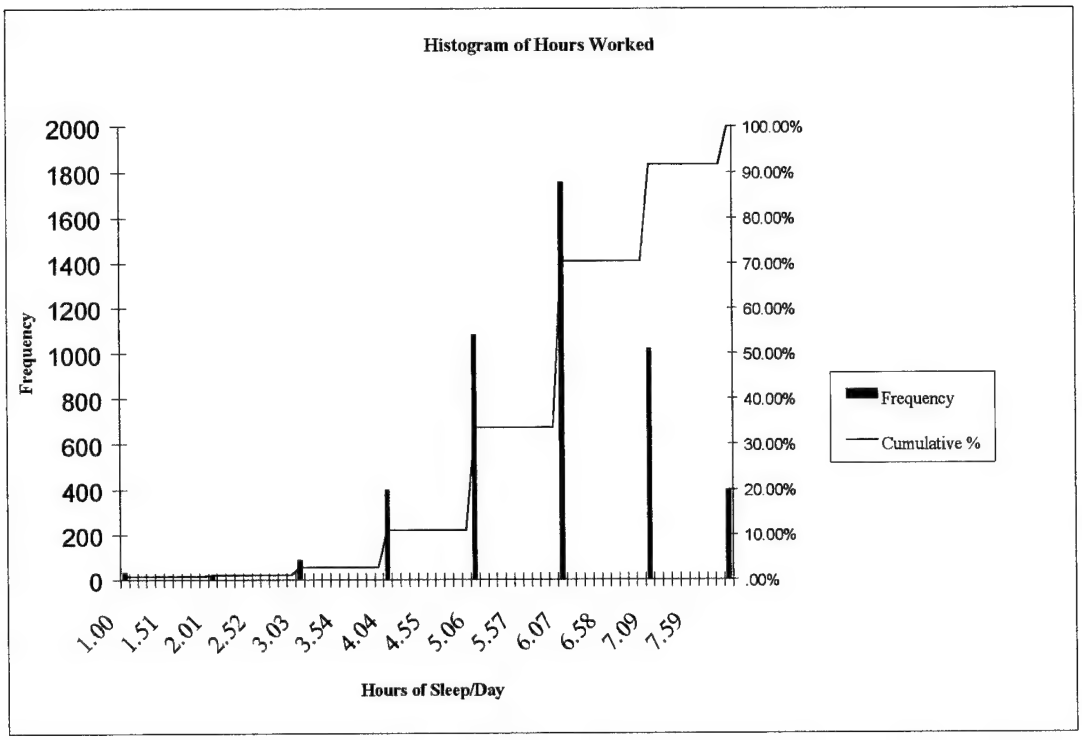
Skewness/Kurtosis tests for Normality: TOTAL SAMLPE HOURS of WORK – TRANSFORMED				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Nework	0.347	0.000	.	0.0000

Shapiro-Francia W' test for normal data: TOTAL SAMLPE HOURS of WORK					
Variable	Obs	W'	V'	z	Pr>z
nework	4760	0.98988	11.876	3.313	0.00046

Analysis of Variance: TOTAL SAMLPE - Hours of Work					
Source	SS	df	MS	F	Prob > F
Between groups	2905.7043	13	223.515716	22.93	0.0000
Within groups	46263.203	4746	9.74783039		
Total	49168.9074	4759	10.3317729		
Bartlett's test for equal variances: chi2(13)=112.2876. Prob>chi2 = 0.000					

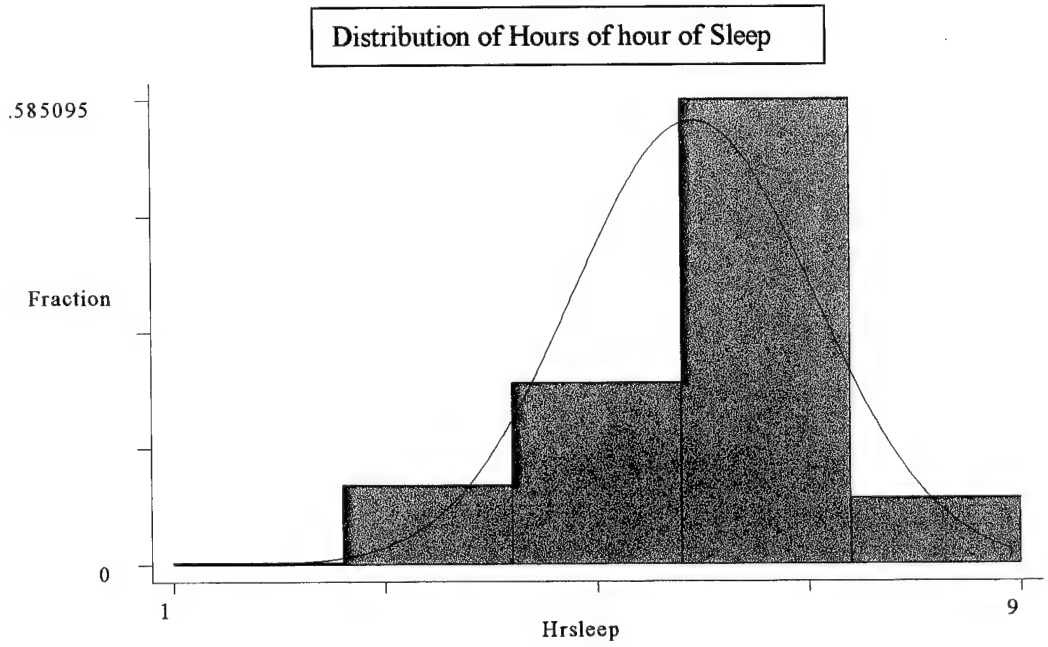
Equality of populations (Kruskal-Wallis Test): **TOTAL Sample - HOURS of WORK**		
CMF	Obs	RankSum
Administration	380	954538.50
Air Defense	219	644286.00
Armor	164	307757.50
Aviators	227	522335.50
Engineer	832	1881467.50
Field Artillery	407	760291.50
Infantry	362	752212.50
Logistics	831	2007395.50
Maintenance	124	214103.00
Medical	162	482555.00
Military Intel	287	703584.50
Military Police	467	1411471.00
Signal	262	620448.50
Transportation	36	68733.50
Chi-squared = 309.469 with 13 d.f.		
Probability = 0.0001		





SLEEP:

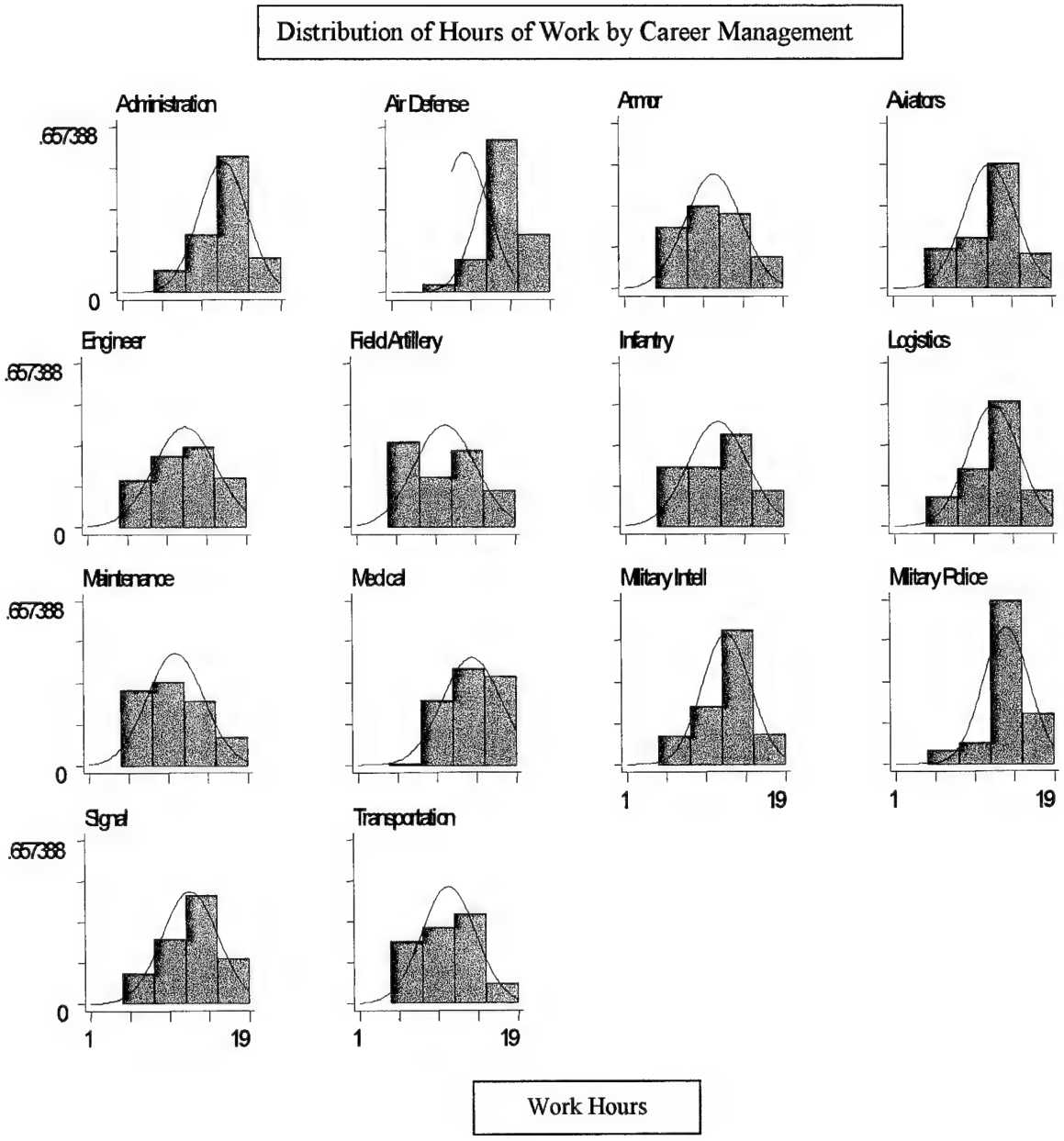
Skewness/Kurtosis tests for Normality: **TOTAL SAMLPE HOURS of SLEEP**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.000	0.875	43.76	0.0000

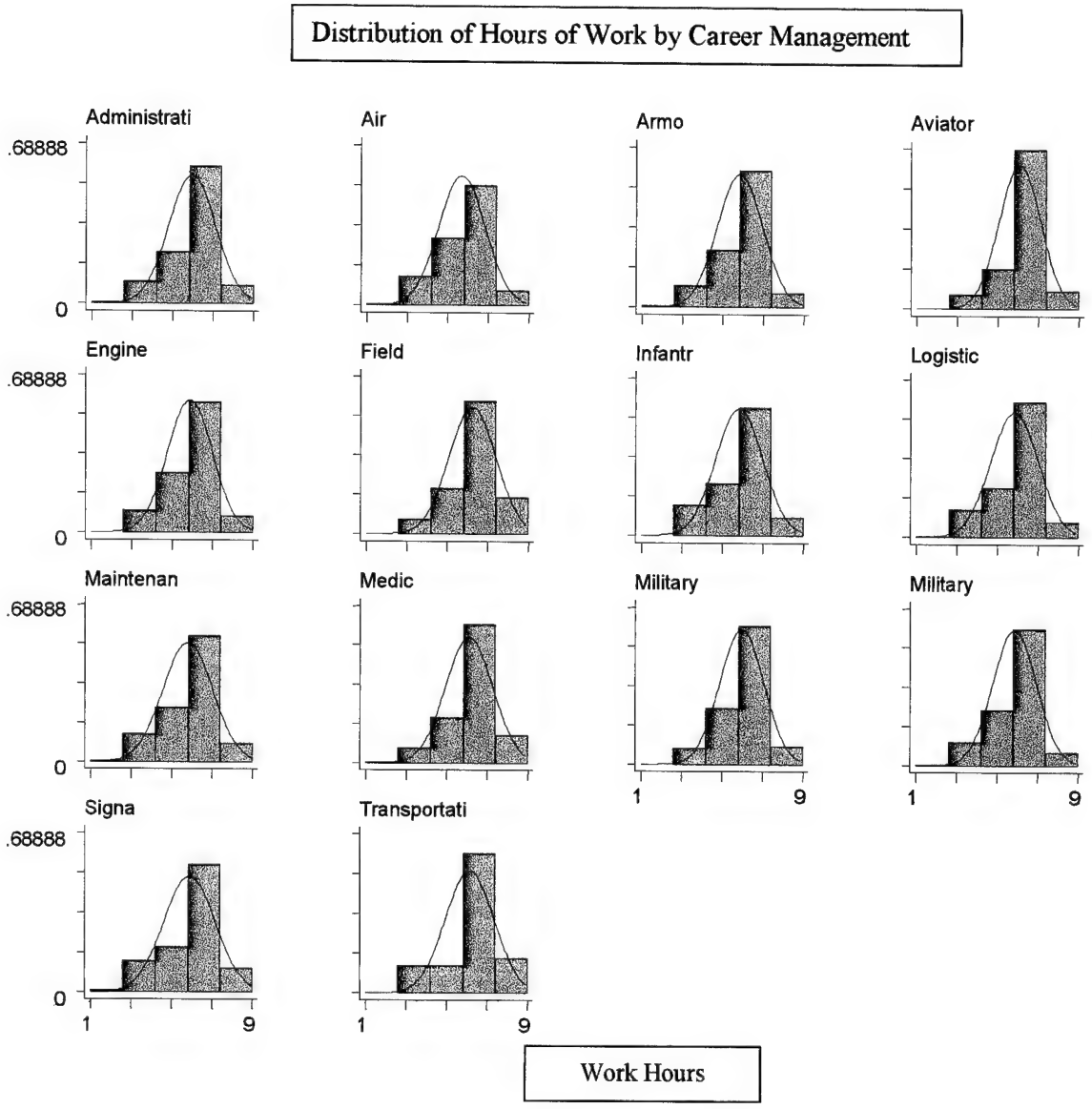


Shapiro-Francia W' test for normal data: **TOTAL SAMLPE HOURS of SLEEP**					
Variable	Obs	W'	V'	z	Pr>z
Hrsleep	4683	0.99884	1.368	0.669	0.25169

Analysis of Variance: **TOTAL SAMLPE - HOURS of SLEEP**					
Source	SS	df	MS	F	Prob > F
Between groups	79.0992627	13	6.08455867	4.69	0.0000
Within groups	6053.87191	4669	1.29660996		
Total	6132.97117	4682	1.30990414		
Bartlett's test for equal variances:chi2(13)= 20.8298. Prob>chi2= 0.076					

Equality of populations (Kruskal-Wallis Test): **TOTAL SAMLPE - HOURS of SLEEP**		
CMF	Obs	RankSum
Administration	380	905993.50
Air Defense	216	446551.50
Armor	160	359693.00
Aviators	225	571622.00
Engineer	823	1873565.00
Field Artillery	394	1058641.00
Infantry	336	750472.00
Logistics	830	1896184.50
Maintenance	122	270470.00
Medical	162	413401.50
Military Intel	284	682154.50
Military Police	460	1050646.50
Signal	258	602430.50
Transportation	33	85760.50
chi-squared = 53.688 with 13 d.f.		
Probability = 0.0001		


Distribution of Hours of Work by Career Management
Administration
Air Defense
Armor
Aviators
Engineer
Field Artillery
Infantry
Logistics
Maintenance
Medical
Military Intell
Military Police
Signal
Transportation
.657388
0
1
19
Work Hours



ADMINISTRATION

WORK:

SKEWNESS/KURTOSIS TEST FOR NORMALITY:**ADMINISTRATION WORK HOURS**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.385	0.064	4.20	0.1223

Shapiro-Wilk W test for normal data: **ADMINISTRATION HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	380	0.98785	3.194	2.757	0.00292

SLEEP:

SKEWNESS/KURTOSIS TESTS FOR NORMALITY: **ADMINISTRATION HOURS of SLEEP**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.005	0.558	7.88	0.0194

Shapiro-Wilk W test for normal data: **ADMINISTRATION HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	380	0.98692	3.441	2.933	0.00168

Skewness/Kurtosis tests for Normality: **ADMINISTRATION HOURS OF SLEEP - TRANSFORMED**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
thrsleep	0.774	0.195	1.77	0.4127

Shapiro-Wilk W test for normal data: **ADMINISTRATION HOUR OF SLEEP – TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
thrsleep	380	0.99589	1.081	0.184	0.42700

AIR DEFENSE

WORK:

Skewness/Kurtosis tests for Normality: **AIR DEFENSE HOURS of WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.848	0.210	1.62	0.4440

Shapiro-Wilk W test for normal data- **AIR DEFENSE HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	219	0.99425	0.928	-0.173	0.56884

SLEEP:

Skewness/Kurtosis tests for Normality: **AIR DEFENSE HOURS of SLEEP**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.401	0.438	1.32	0.5172

Shapiro-Wilk W test for normal data- **AIR DEFENSE**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	216	0.99309	1.102	0.225	0.41088

ARMOR

WORK:

Skewness/Kurtosis tests for Normality: **ARMOR HOURS of WORK**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.000	0.324	11.85	0.0027

Shapiro-Wilk W test for normal data: **ARMOR HOURS OF WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	164	0.94931	6.368	4.217	0.00001

Skewness/Kurtosis tests for Normality: **ARMOR HOURS of WORK – TRANSFORMED**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
nework	0.011	0.017	10.56	0.0051

Shapiro-Wilk W test for normal data: **ARMOR HOURS of WORK - TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
nework	164	0.97353	3.325	2.737	0.00310

SLEEP:

Skewness/Kurtosis tests for Normality: **ARMOR HOURS OF SLEEP**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.081	0.197	4.78	0.0917

Shapiro-Wilk W test for normal data: **ARMOR HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	160	0.98605	1.716	1.228	0.10970

AVIATORS

WORK:

Skewness/Kurtosis tests for Normality: **AVIATORS HOURS of WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.470	0.062	4.04	0.1329

Shapiro-Wilk W test for normal data: **AVIATORS HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	227	0.98354	2.743	2.336	0.00974

SLEEP:

Skewness/Kurtosis tests for Normality: **AVIATORS HOURS of SLEEP**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.017	0.133	7.45	0.0241

Shapiro-Wilk W test for normal data: **AVIATORS HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	225	0.98685	2.175	1.798	0.03605

ENGINEERS

WORK:

Skewness/Kurtosis tests for Normality: **ENGINEERS HOURS of WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.000	0.000	.	0.0000

Shapiro-Wilk W test for normal data: **ENGINEERS HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	832	0.96030	21.181	7.504	0.00000

Skewness/Kurtosis tests for Normality: **ENGINEERS HOURS of WORK TRANSFORMED**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Nework |	0.972	0.000	.	0.0000

Shapiro-Wilk W test for normal data: **ENGINEERS HOURS of WORK – TRANSFORMED**					
Variable |	Obs	W	V	z	Pr > z
Nework |	832	0.98195	9.628	5.566	0.00000

SLEEP:

Skewness/Kurtosis tests for Normality: **ENGINEERS HOURS of SLEEP**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep |	0.070	0.809	3.34	0.1879

Shapiro-Wilk W test for normal data: **ENGINEERS HOURS of SLEEP**					
Variable |	Obs	W	V	z	Pr > z
Hrsleep |	823	0.99692	1.628	1.198	0.11550

MILITARY INTELLIGENCE

WORK:

Skewness/Kurtosis tests for Normality: **MILITARY INTELLIGENCE HOURS of WORK**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork |	0.410	0.180	2.49	0.2876

Shapiro-Wilk W test for normal data: MILITARY INTELLIGENCE HOURS of WORK					
Variable |	Obs	W	V	z	Pr > z
Hrswork |	287	0.98865	2.325	1.976	0.02408

SLEEP:

Skewness/Kurtosis tests for Normality: **MILITARY INTELLIGENCE HOURS of SLEEP**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep |	0.195	0.950	1.70	0.4278

Shapiro-Wilk W test for normal data **MILITARY INTELLIGENCE HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	284	0.99511	0.992	-0.020	0.50795

FIELD ARTILLERY

WORK:

Skewness/Kurtosis tests for Normality: **FIELD ARTILLERY HOURS OF WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.000	0.000	43.60	0.0000

Shapiro-Wilk W test for normal data: **FIELD ARTILLERY HOURS OF WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	407	0.96603	9.498	5.361	0.00000

Shapiro-Wilk W test for normal data: **FIELD ARTILLERY HOURS OF WORK – TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
nework	407	0.98182	5.083	3.872	0.00005

SLEEP:

Skewness/Kurtosis tests for Normality: **FIELD ARTILLERY HOURS OF SLEEP**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.120	0.005	9.54	0.0085

Shapiro-Wilk W test for normal data: **FIELD ARTILLERY HOURS OF SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	394	0.99260	2.011	1.661	0.04835

INFANTRY

WORK:

Skewness/Kurtosis tests for Normality: **INFANTRY HPURS OF WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.012	0.000	27.93	0.0000

Shapiro-Wilk W test for normal data: INFANTRY HOURS OF WORK					
Variable	Obs	W	V	z	Pr > z
Hrswork	362	0.98133	4.702	3.666	0.00012

Shapiro-Wilk W test for normal data: **INFANTRY HOURS OF WORK – TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
nework	362	0.99225	1.953	1.585	0.05649

SLEEP:

Skewness/Kurtosis tests for Normality: **INFANTRY HOURS OF SLEEP**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.517	0.200	2.07	0.3554

Shapiro-Wilk W test for normal data: **INFANTRY HOUS OF SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	336	0.99819	0.428	-2.005	0.97753

LOGISTICS

WORK:

Skewness/Kurtosis tests for Normality: **LOGISTICS HOURS OF WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.000	0.010	19.45	0.0001

Shapiro-Wilk W test for normal data: **LOGISTICS HOURS OF WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	831	0.98111	10.069	5.676	0.00000

Shapiro-Wilk W test for normal data: **LOGISTICS HOURS OF WORK – TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
nework	831	0.98992	5.373	4.132	0.00002

SLEEP:

Skewness/Kurtosis tests for Normality: **LOGISTICS HOURS OF SLEEP**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep |	0.000	0.451	17.02	0.0002

Shapiro-Wilk W test for normal data: **LOGISTICS HOURS OF SLEEP**					
Variable |	Obs	W	V	z	Pr > z
Hrsleep |	830	0.99224	4.130	3.485	0.00025

Shapiro-Wilk W test for normal data: **LOGISTICS HOURS OF SLEEP – TRANSFORMED**					
Variable |	Obs	W	V	z	Pr > z
newsleep |	830	0.99846	0.818	-0.493	0.68909

SIGNAL

WORK:

Skewness/Kurtosis tests for Normality: **SIGNAL HOURS of WORK**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork |	0.005	0.018	11.85	0.0027

Shapiro-Wilk W test for normal data**: SIGNAL HOURS OF WORK**

Variable |	Obs	W	V	z	Pr > z
Hrswork |	262	0.96748	6.146	4.234	0.00001

Skewness/Kurtosis tests for Normality**: SIGNAL HOURS OF WORK - TRANSFORMED**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
thrswork |	0.944	0.011	6.29	0.0431

Shapiro-Wilk W test for normal data: **SIGNAL HOUR OF WORK - TRANSFORMED**					
Variable |	Obs	W	V	z	Pr > z
thrswork |	262	0.98576	2.692	2.309	0.01046

SLEEP:

Skewness/Kurtosis tests for Normality: **SIGNAL HOURS of SLEEP**				
------- joint -------				
Variable |	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep |	0.021	0.886	5.34	0.0693

Shapiro-Wilk W test for normal data: **SIGNAL HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	258	0.98595	2.620	2.245	0.01240

MAINTENANCE

WORK:

Skewness/Kurtosis tests for Normality: **MAINTENANCE HOURS OF WORK**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.000	0.920	11.34	0.0034

Shapiro-Wilk W test for normal data: **MAINTENANCE HOURS OF WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	124	0.94033	5.903	3.985	0.00003

Shapiro-Wilk W test for normal data: **MAINTENANCE HOURS OF WORK - TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
Nework	124	0.99530	0.465	-1.719	0.95721

SLEEP:

Shapiro-Wilk W test for normal data: **MAINTENANCE HOURS OF SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	122	0.98650	1.317	0.618	0.26839

Skewness/Kurtosis tests for Normality: **MAINTENANCE HOURS OF SLEEP**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.121	0.494	2.94	0.2303

Medical

WORK:

Shapiro-Wilk W test for normal data: **MEDICAL HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	162	0.94240	7.160	4.481	0.00000

Skewness/Kurtosis tests for Normality: **MEDICAL HOURS of WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.075	0.000	.	0.0000

Shapiro-Wilk W test for normal data: **MEDICAL HOURS of WORK – TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
nework	162	0.95951	5.033	3.678	0.00012

SLEEP:

Skewness/Kurtosis tests for Normality: **MEDICAL HOURS OF SLEEP**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.050	0.272	5.05	0.0801

Shapiro-Wilk W test for normal data: **MEDICAL HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	162	0.97484	3.127	2.595	0.00473

Military Police

WORK:

Skewness/Kurtosis tests for Normality: **MILITARY POLICE HOURS of WORK**				
------- joint -------				
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.025	0.287	6.13	0.0467

Shapiro-Wilk W test for normal data: **MILITARY POLICE HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	467	0.98520	4.681	3.699	0.00011

Skewness/Kurtosis tests for Normality: **MILITARY POLICE HOURS of WORK - TRANSFORMED**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
thrswork	0.984	0.665	0.19	0.9103

Shapiro-Wilk W test for normal data: **MILITARY POLICE HOURS of WORK - TRANSFORMED**					
Variable	Obs	W	V	z	Pr > z
thrswork	467	0.98919	3.420	2.947	0.00161

SLEEP:

Skewness/Kurtosis tests for Normality: **MILITARY POLICE**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.124	0.548	2.74	0.2547

Shapiro-Wilk W test for normal data: **MILITARY POLICE HOURS OF SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	460	0.99443	1.740	1.326	0.09240

TRANSPORTATION

WORK:

Skewness/Kurtosis tests for Normality: **TRANSPORTATION HOURS of WORK**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrswork	0.149	0.616	2.51	0.2851

Shapiro-Wilk W test for normal data: **TRANSPORTATION HOURS of WORK**					
Variable	Obs	W	V	z	Pr > z
Hrswork	36	0.95615	1.599	0.982	0.16315

SLEEP:

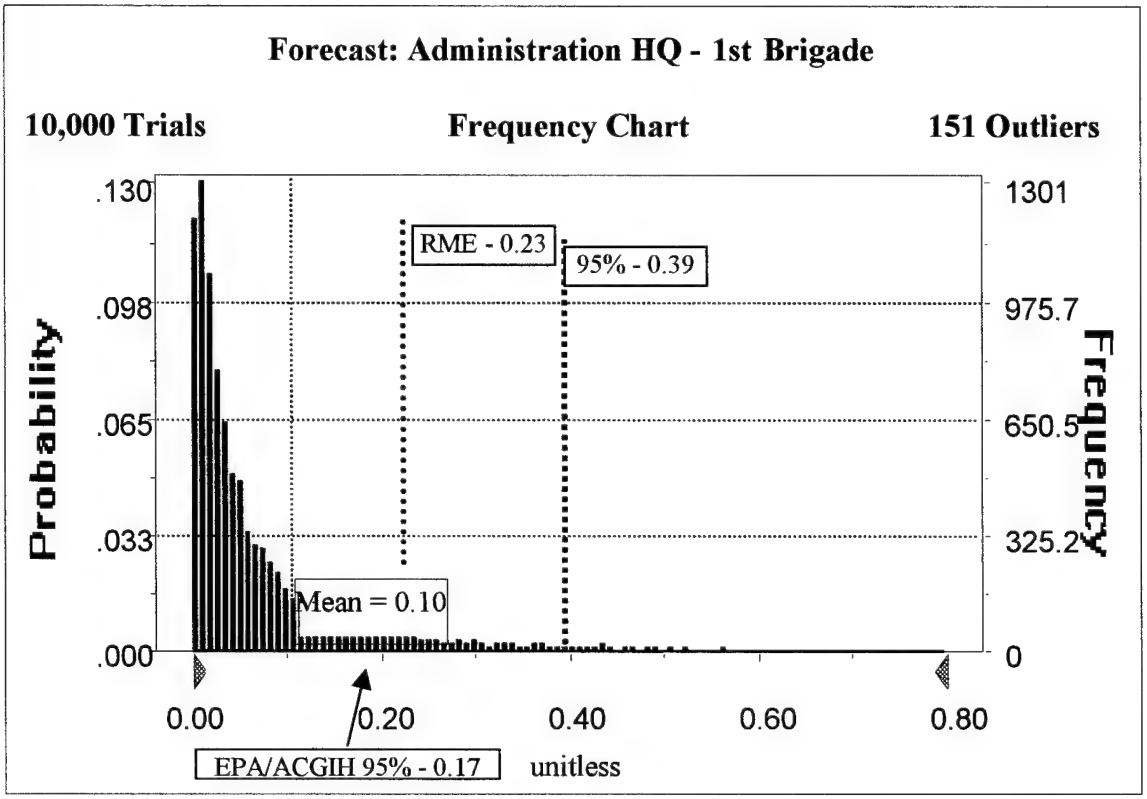
Skewness/Kurtosis tests for Normality: **TRANSPORTATION HOURS of SLEEP**				
	------- joint -------			
Variable	Pr(Skewness)	Pr(Kurtosis)	adj chi-sq(2)	Pr(chi-sq)
Hrsleep	0.616	0.551	0.63	0.7296

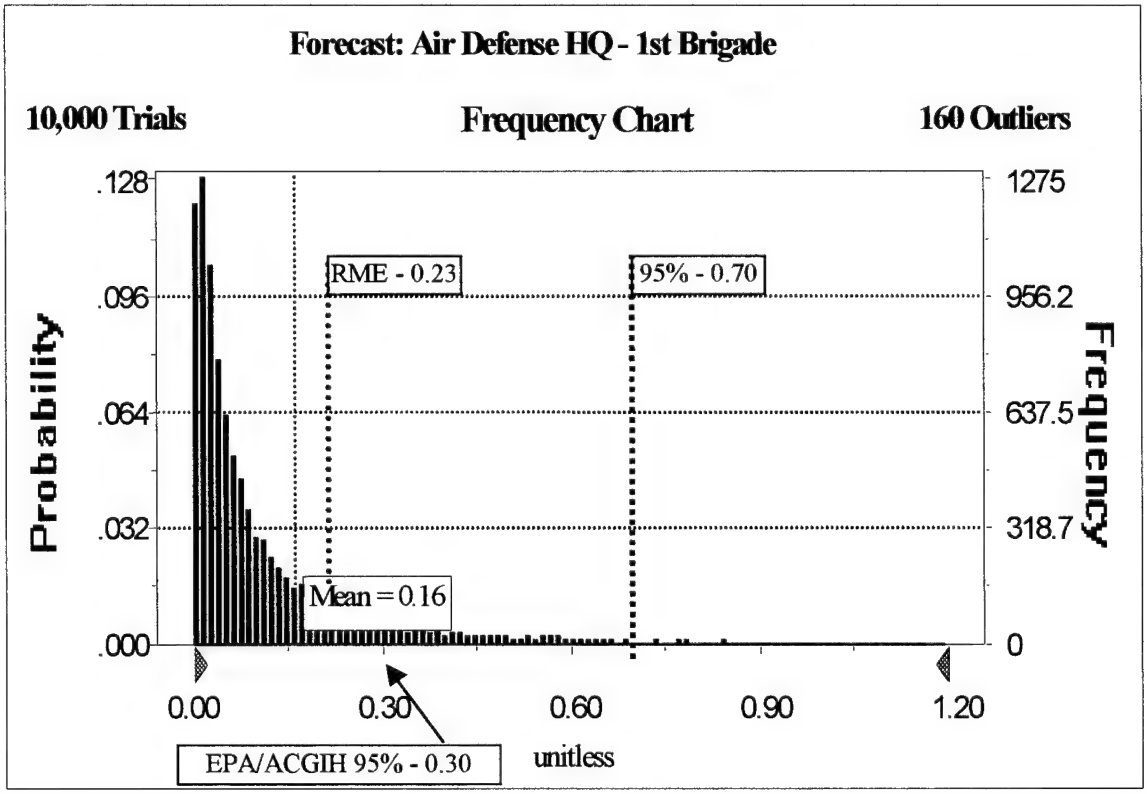
Shapiro-Wilk W test for normal data: **TRANSPORTATION HOURS of SLEEP**					
Variable	Obs	W	V	z	Pr > z
Hrsleep	33	0.99529	0.161	-3.802	0.99993

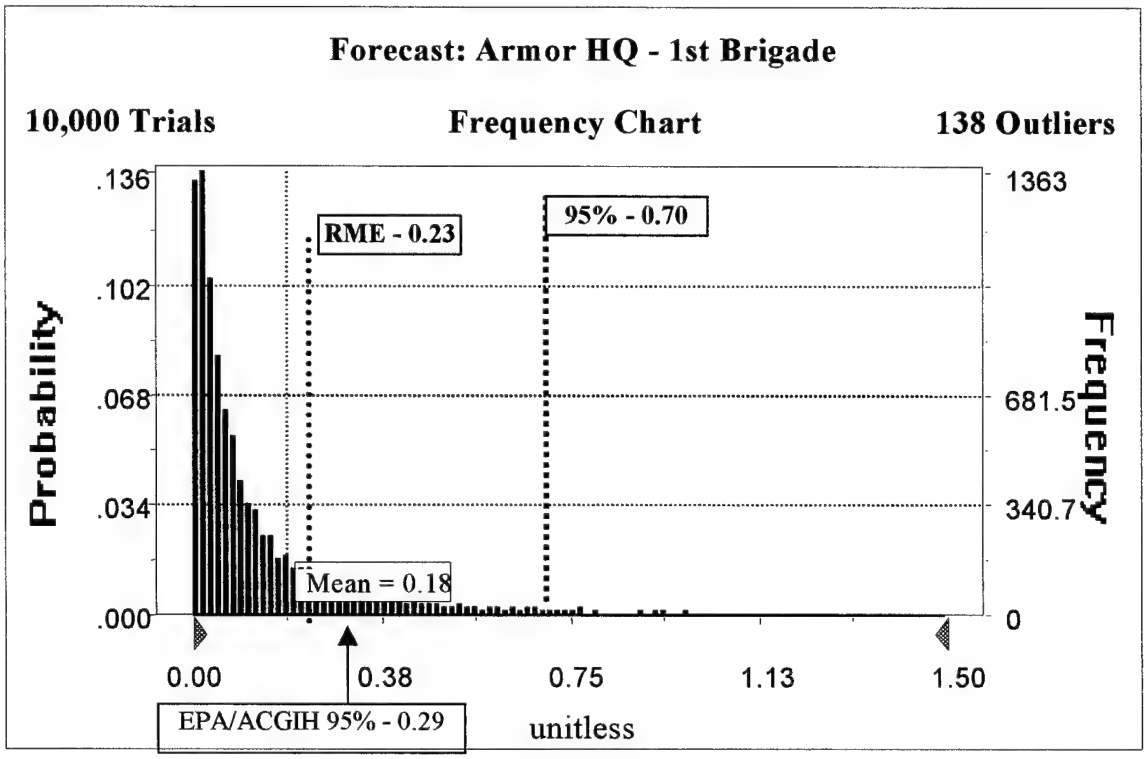
Appendix I: Exposure Duration

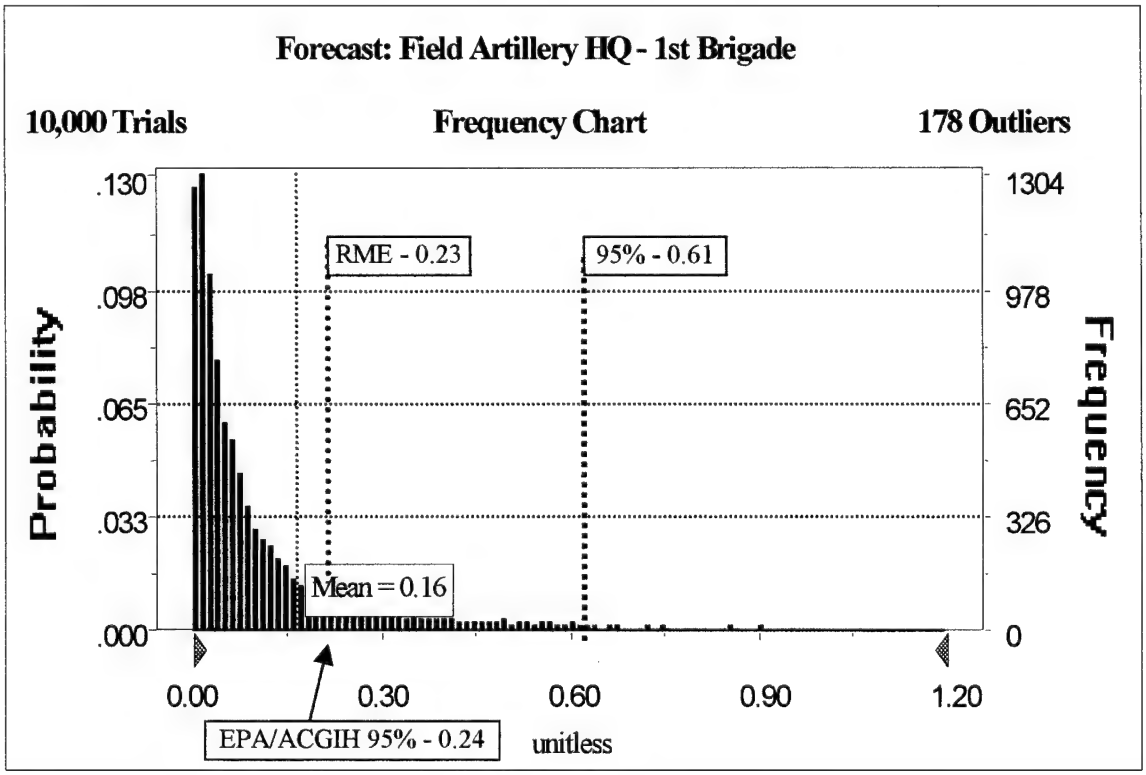
Time In Theatre (Bosnia)				
		Time in Days		
Career Management Field	N	Min	Max	Average
Administration	2023	2	601	226.09
Infantry	5539	1	776	176
Engineer	2745	1	722	232.27
Field Artillery	2979	1	659	229.74
Air Defense	894	10	541	139.7
Signals	4123	1	777	222.26
Armor	2765	10	689	238.26
Maintenance	8521	1	743	230.22
Logistics	7235	1	705	223.7
Medical	2345	1	767	247.77
Transportation	1956	1	802	250.34
Aviation	1451	1	787	230.08
Military Police	2903	1	691	241.66
Military Intelligence	1034	1	772	223.6

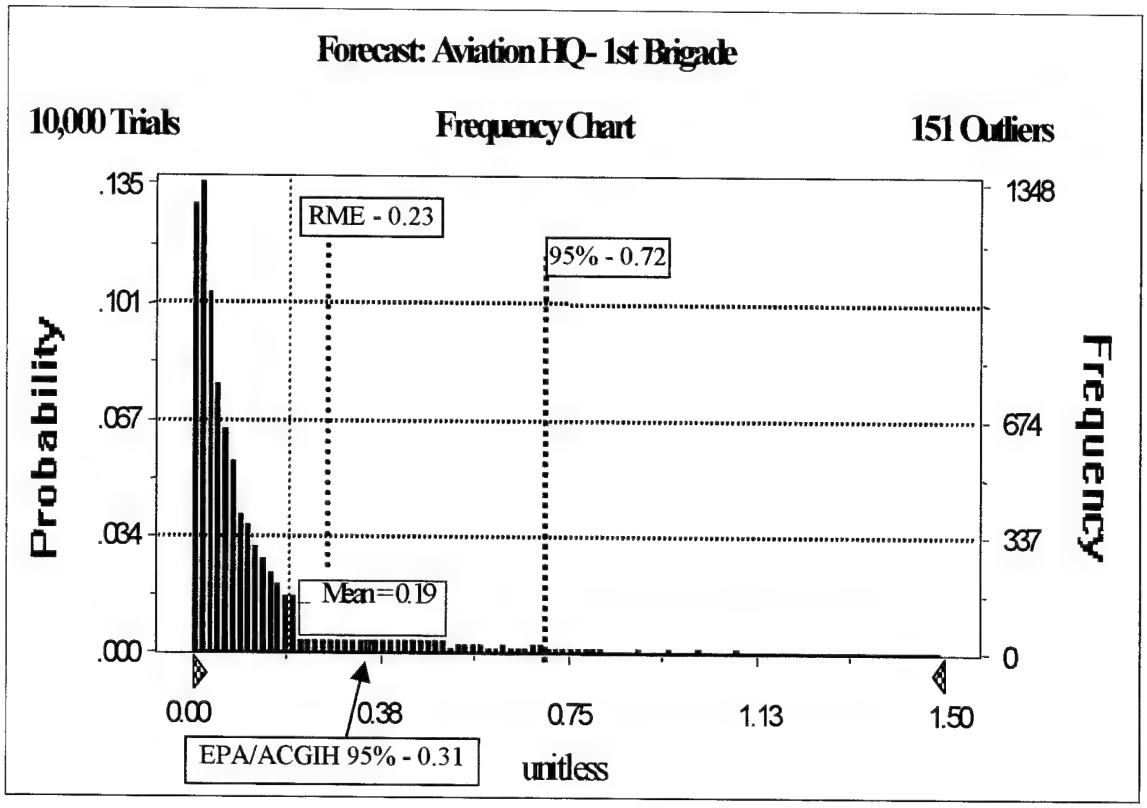
Appendix J: Hazard Quotient Distributions

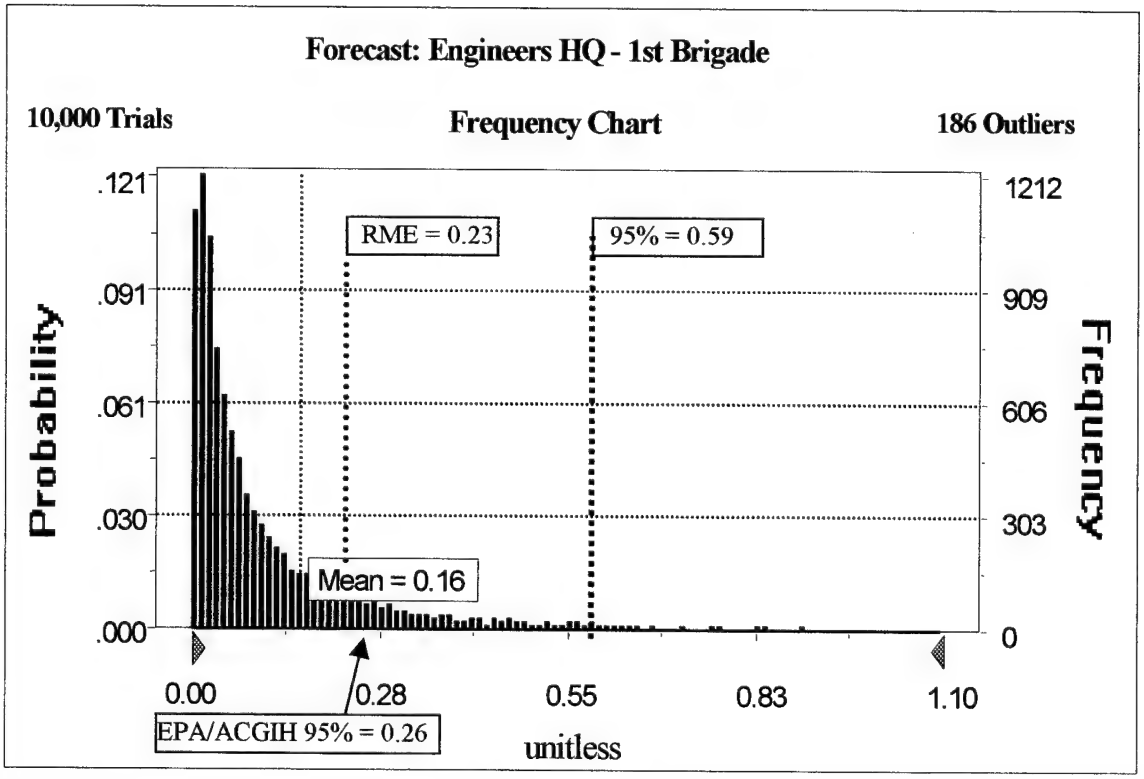


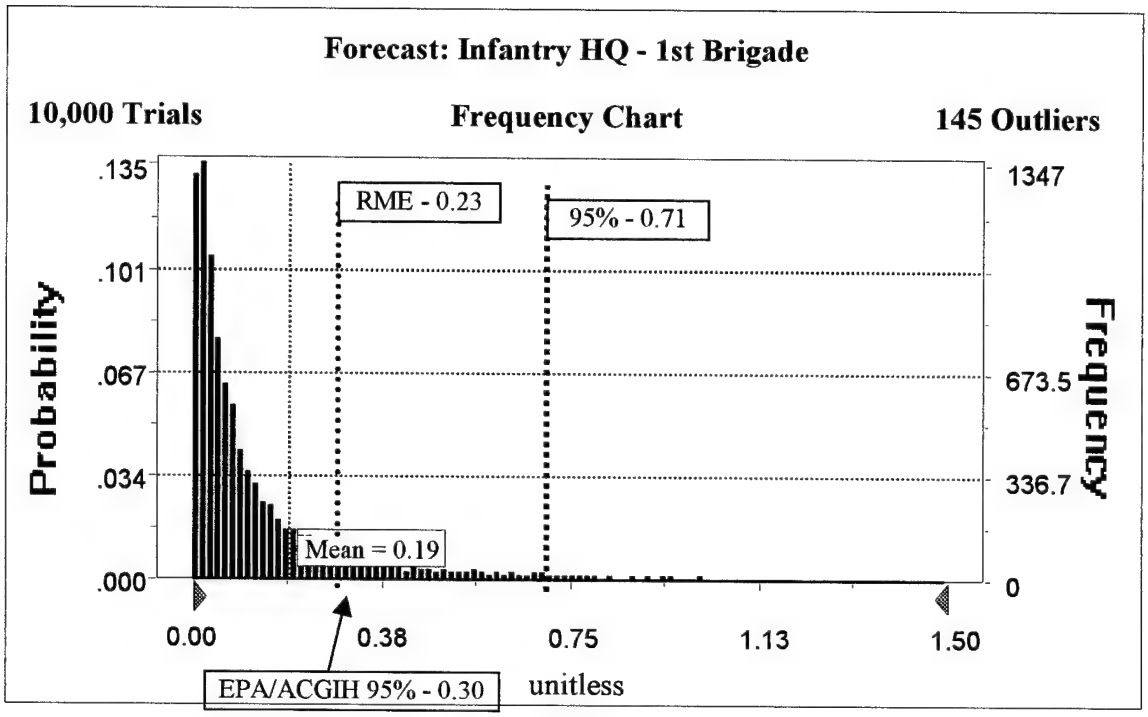


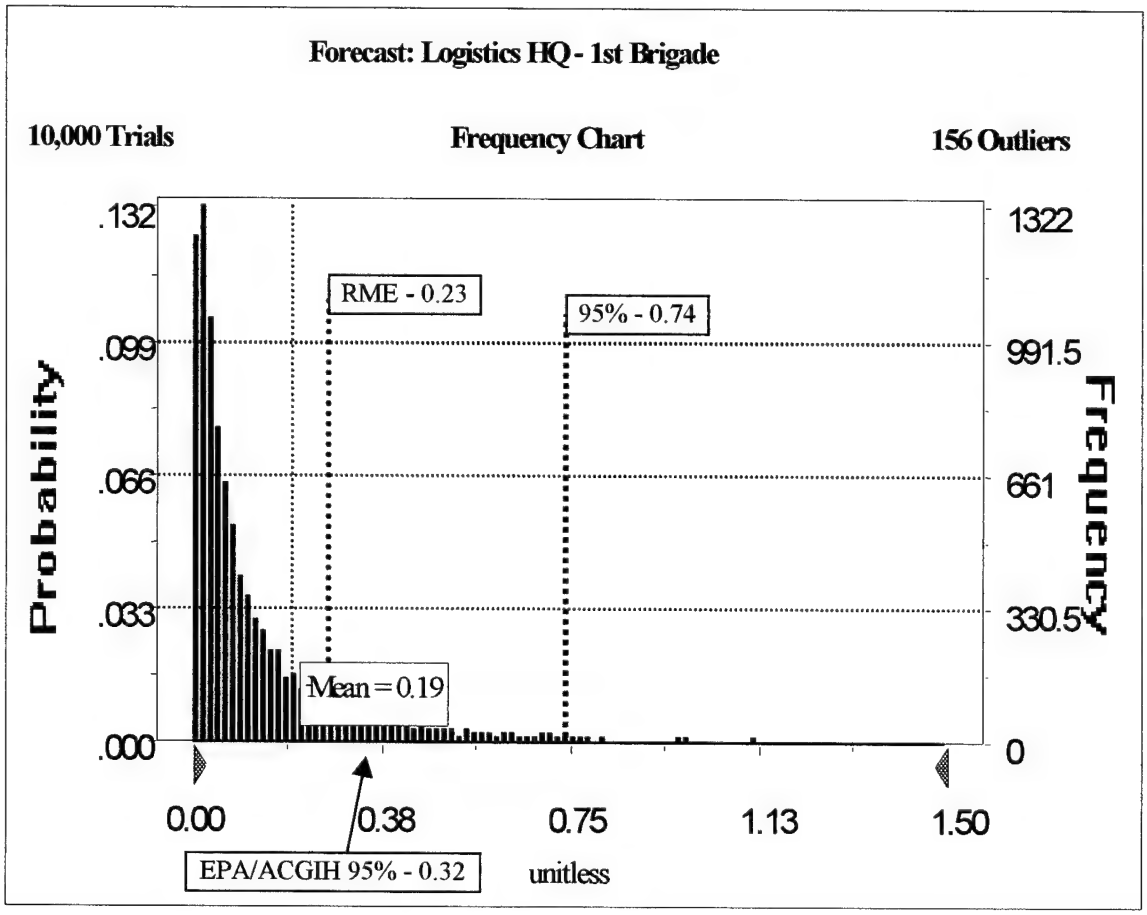

Forecast: Armor HQ - 1st Brigade
10,000 Trials
Frequency Chart
138 Outliers
.136
.102
.068
.034
.000
1363
681.5
340.7
0
Probability
Frequency
RME - 0.23
95% - 0.70
Mean = 0.18
0.00
0.38
0.75
1.13
1.50
EPA/ACGIH 95% - 0.29
unitless

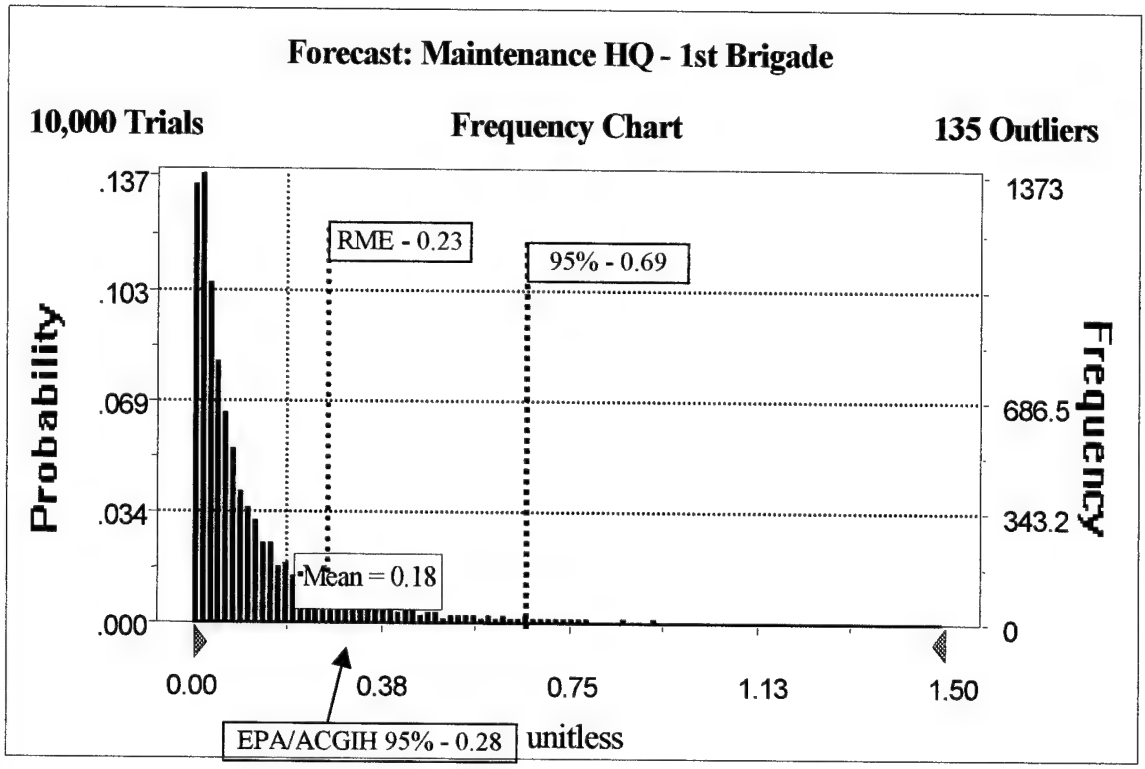

Forecast: Field Artillery HQ - 1st Brigade
10,000 Trials
Frequency Chart
178 Outliers
.130
.098
.065
.033
.000
1304
978
652
326
0
Probability
Frequency
RME - 0.23
95% - 0.61
Mean = 0.16
0.00
0.30
0.60
0.90
1.20
EPA/ACGIH 95% - 0.24
unitless

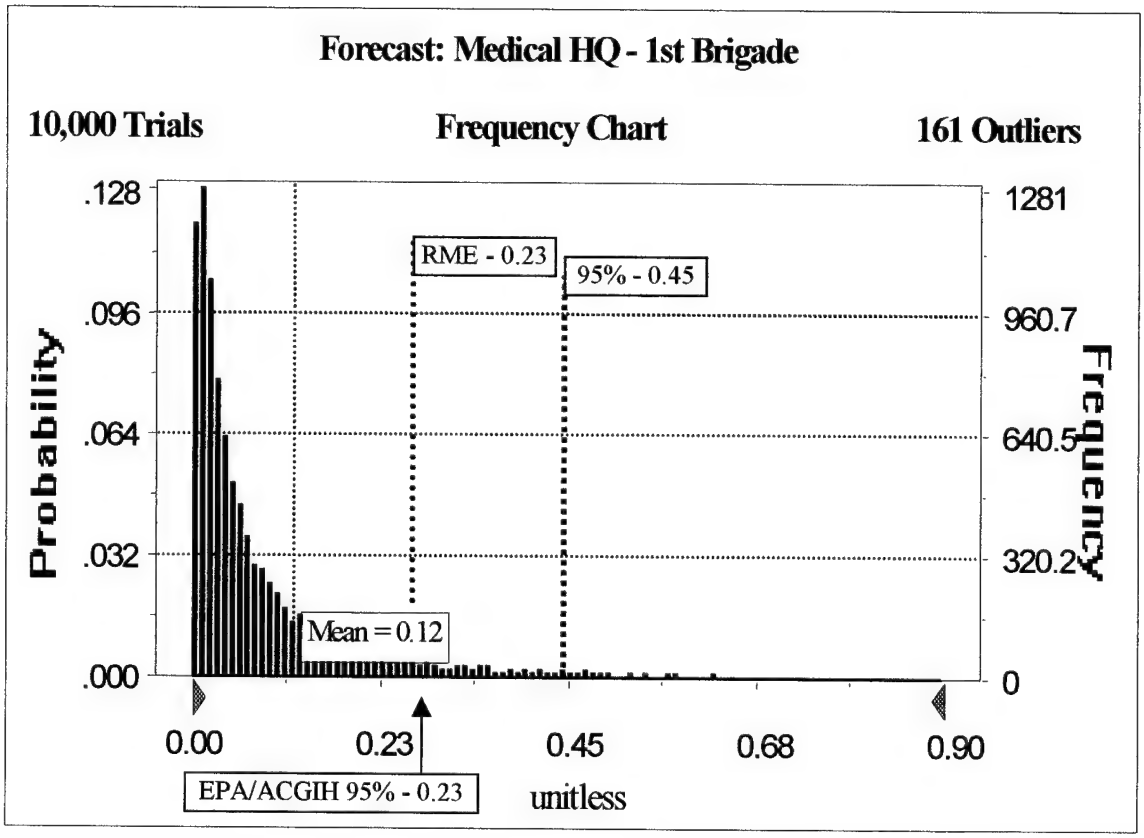

Forecast: Aviation HQ- 1st Brigade
10,000 Trials
Frequency Chart
151 Outliers
.135
.101
.067
.034
.000
Probability
1348
674
337
0
Frequency
RME - 0.23
95% - 0.72
Mean=0.19
0.00
0.38
0.75
1.13
1.50
EPA/ACGIH 95% - 0.31
unitless

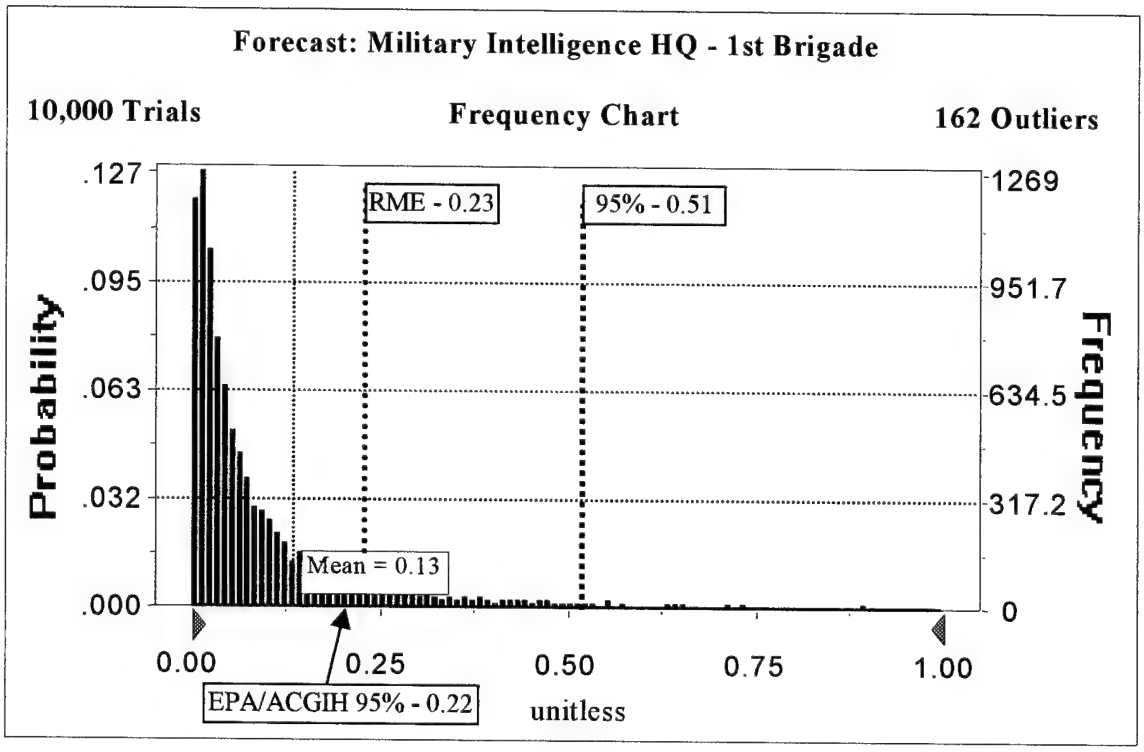

Forecast: Engineers HQ - 1st Brigade
10,000 Trials
Frequency Chart
186 Outliers
.121
.091
.061
.030
.000
Probability
1212
909
606
303
0
Frequency
RME = 0.23
95% = 0.59
Mean = 0.16
0.00
0.28
0.55
0.83
1.10
EPA/ACGIH 95% = 0.26
unitless

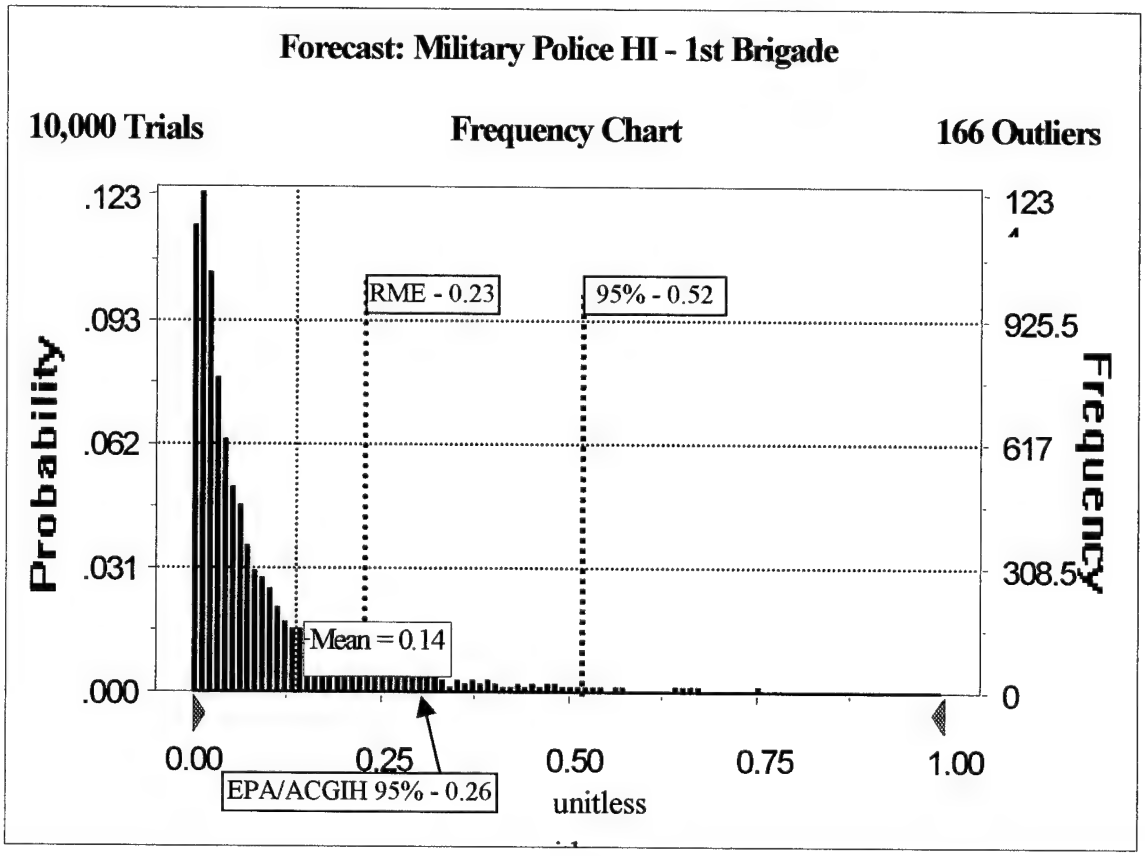

Forecast: Infantry HQ - 1st Brigade
10,000 Trials
Frequency Chart
145 Outliers
.135
.101
.067
.034
.000
Probability
1347
673.5
336.7
0
Frequency
RME - 0.23
95% - 0.71
Mean = 0.19
0.00
0.38
0.75
1.13
1.50
EPA/ACGIH 95% - 0.30
unitless

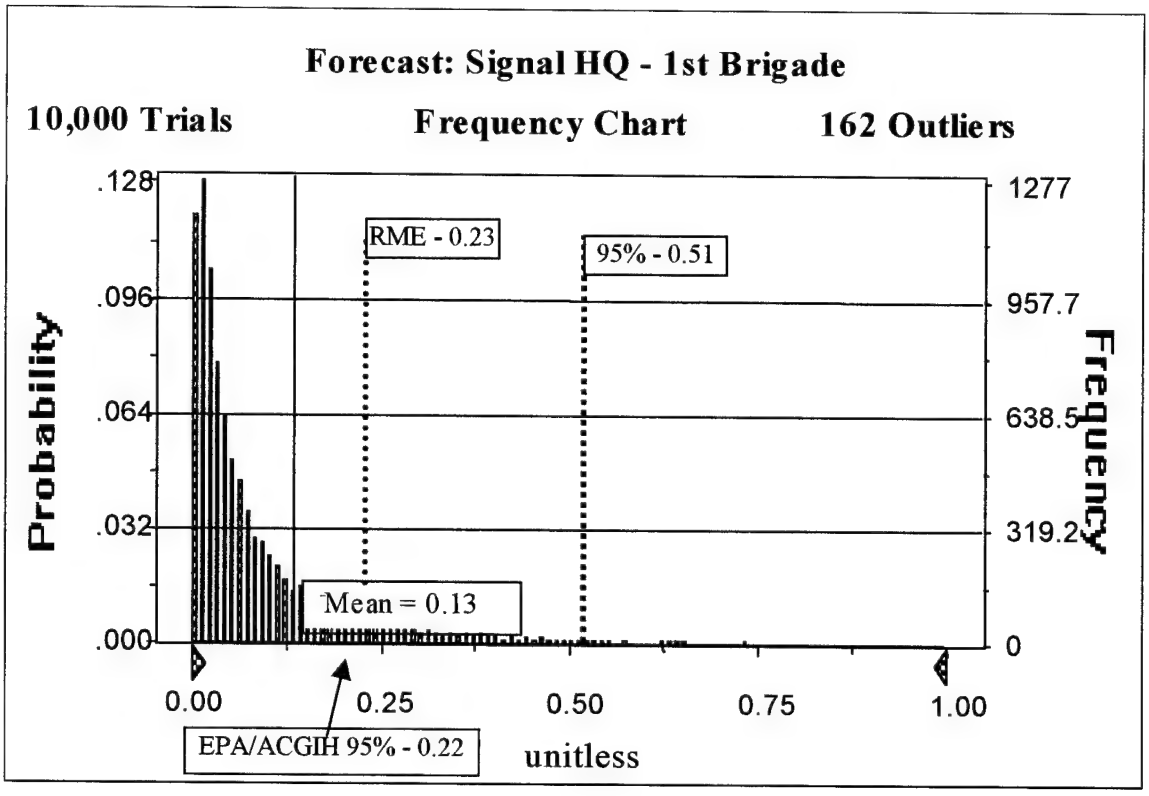

Forecast: Logistics HQ - 1st Brigade
10,000 Trials
Frequency Chart
156 Outliers
.132
.099
.066
.033
.000
Probability
1322
991.5
661
330.5
0
Frequency
RME - 0.23
95% - 0.74
Mean = 0.19
0.00
0.38
0.75
1.13
1.50
EPA/ACGIH 95% - 0.32
unitless

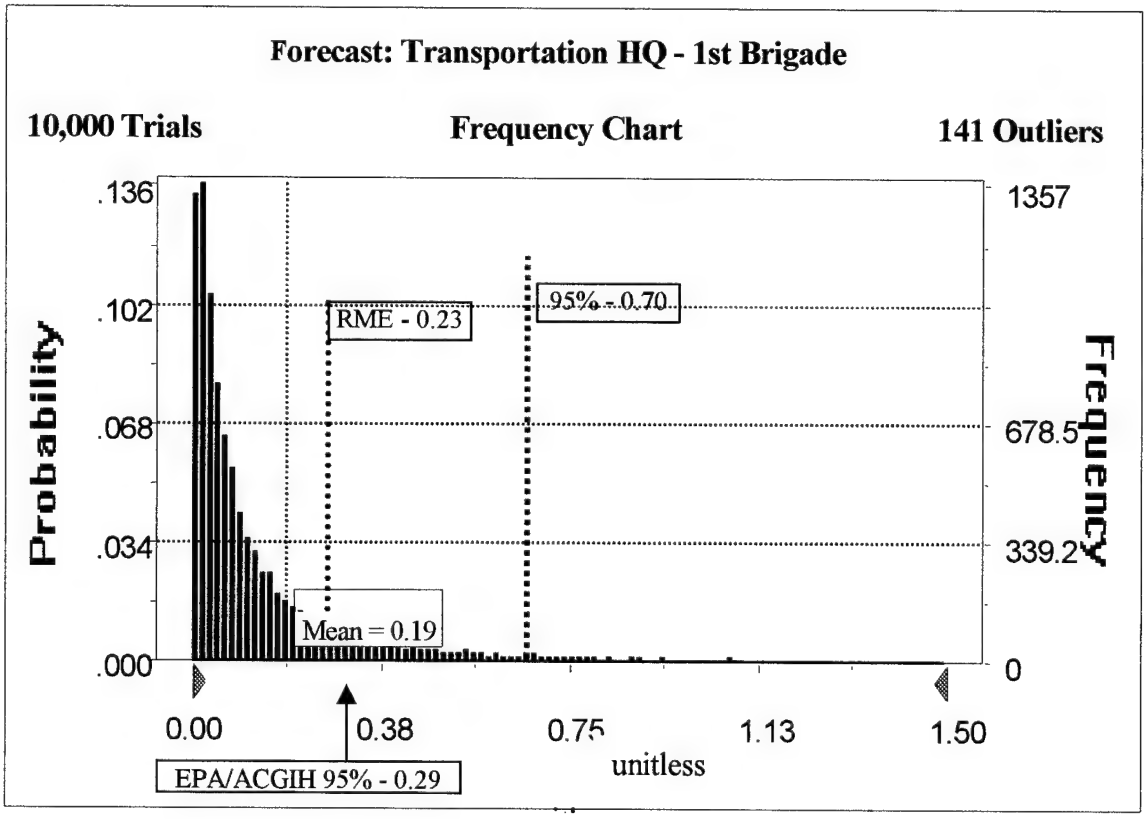

Forecast: Maintenance HQ - 1st Brigade
10,000 Trials
Frequency Chart
135 Outliers
.137
.103
.069
.034
.000
Probability
1373
686.5
343.2
0
Frequency
RME - 0.23
95% - 0.69
Mean = 0.18
0.00
0.38
0.75
1.13
1.50
EPA/ACGIH 95% - 0.28
unitless


Forecast: Medical HQ - 1st Brigade
10,000 Trials
Frequency Chart
161 Outliers
.128
.096
.064
.032
.000
Probability
1281
960.7
640.5
320.2
0
Frequency
RME - 0.23
95% - 0.45
Mean = 0.12
0.00
0.23
0.45
0.68
0.90
EPA/ACGIH 95% - 0.23
unitless

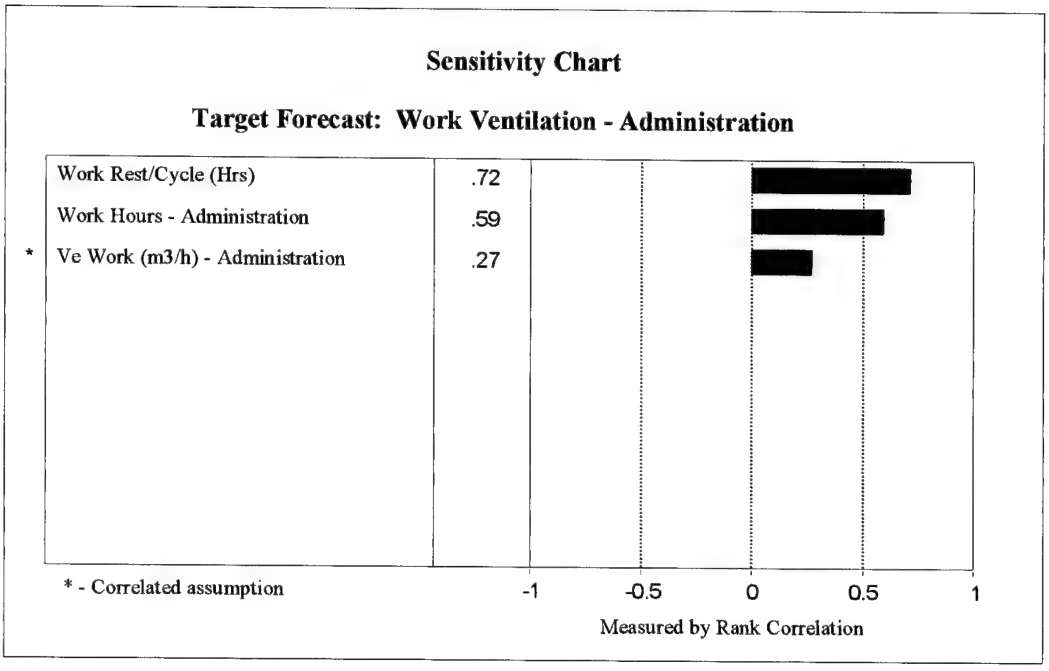

Forecast: Military Intelligence HQ - 1st Brigade
10,000 Trials
Frequency Chart
162 Outliers
.127
.095
.063
.032
.000
Probability
1269
951.7
634.5
317.2
0
Frequency
RME - 0.23
95% - 0.51
Mean = 0.13
0.00
0.25
0.50
0.75
1.00
EPA/ACGIH 95% - 0.22
unitless

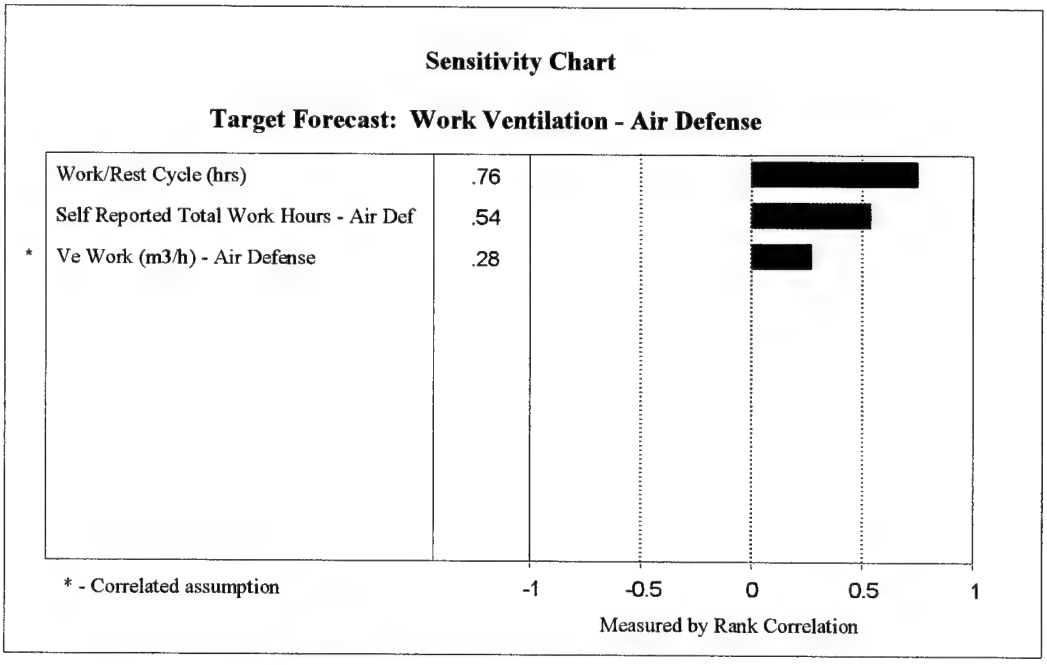

Forecast: Military Police HI - 1st Brigade
10,000 Trials
Frequency Chart
166 Outliers
.123
.093
.062
.031
.000
Probability
123
925.5
617
308.5
0
Frequency
RME - 0.23
95% - 0.52
Mean = 0.14
0.00
0.25
0.50
0.75
1.00
EPA/ACGIH 95% - 0.26
unitless

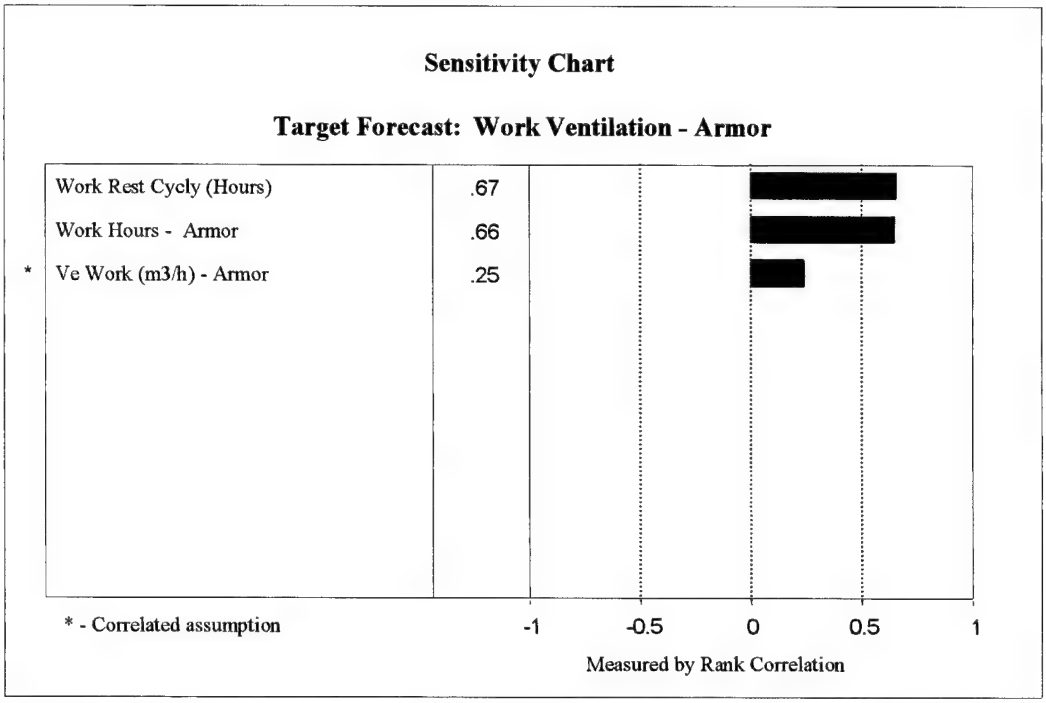

Forecast: Signal HQ - 1st Brigade
10,000 Trials
Frequency Chart
162 Outliers
.128
.096
.064
.032
.000
Probability
1277
957.7
638.5
319.2
0
Frequency
RME - 0.23
95% - 0.51
Mean = 0.13
0.00
0.25
0.50
0.75
1.00
EPA/ACGIH 95% - 0.22
unitless

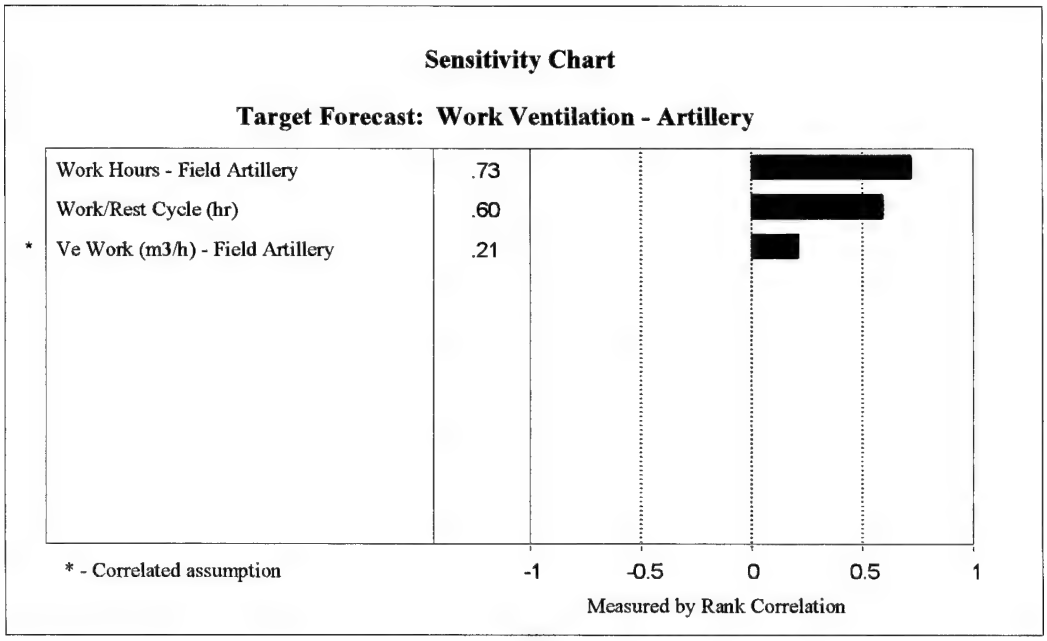

Forecast: Transportation HQ - 1st Brigade
10,000 Trials
Frequency Chart
141 Outliers
.136
.102
.068
.034
.000
Probability
1357
678.5
339.2
0
Frequency
RME - 0.23
95% - 0.70
Mean = 0.19
0.00
0.38
0.75
1.13
1.50
EPA/ACGIH 95% - 0.29
unitless

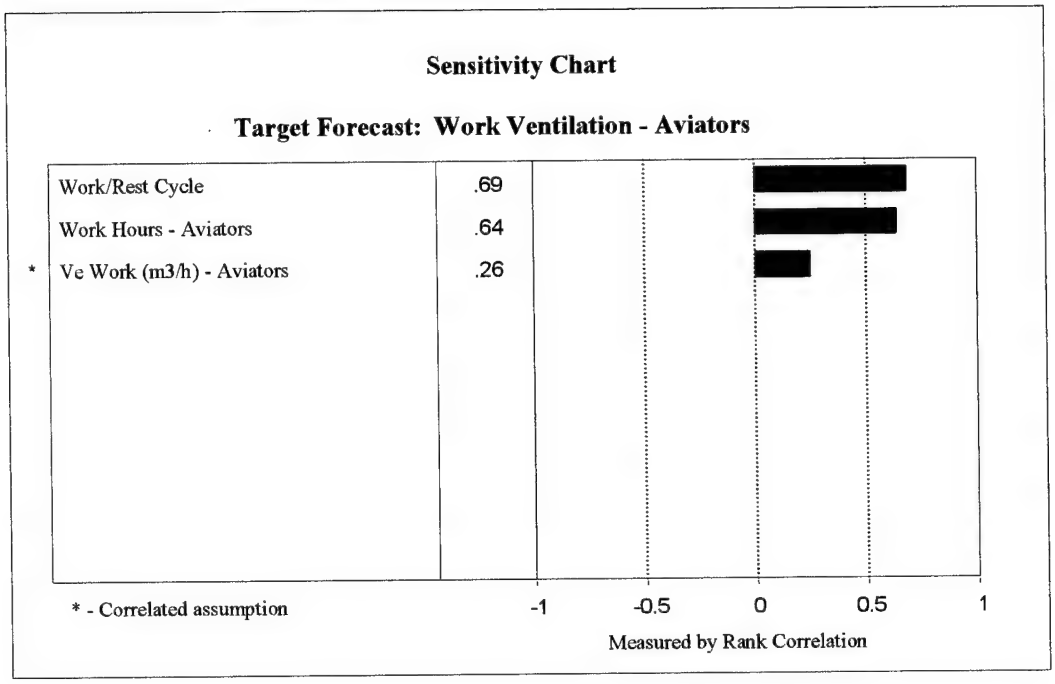
Appendix K: Ventilatory Rate Sensitivity Charts

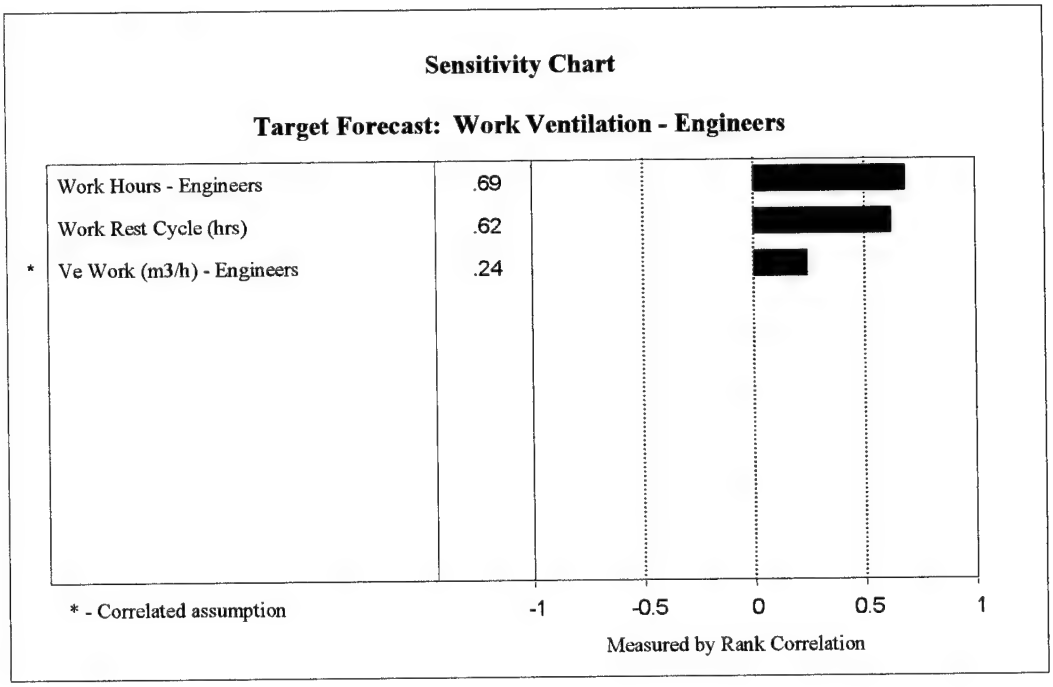


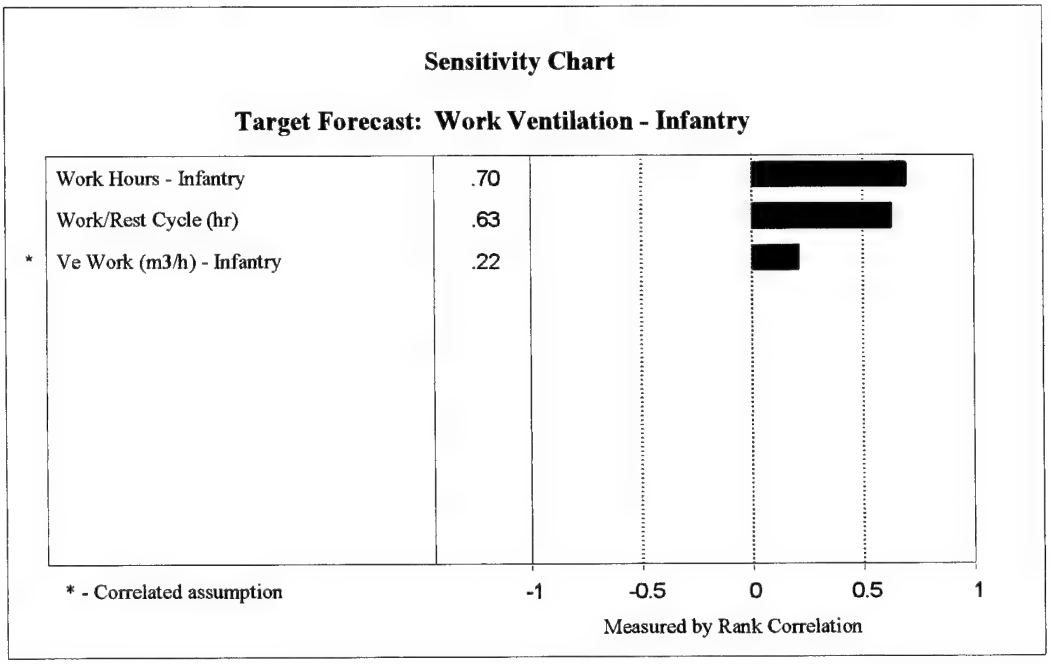


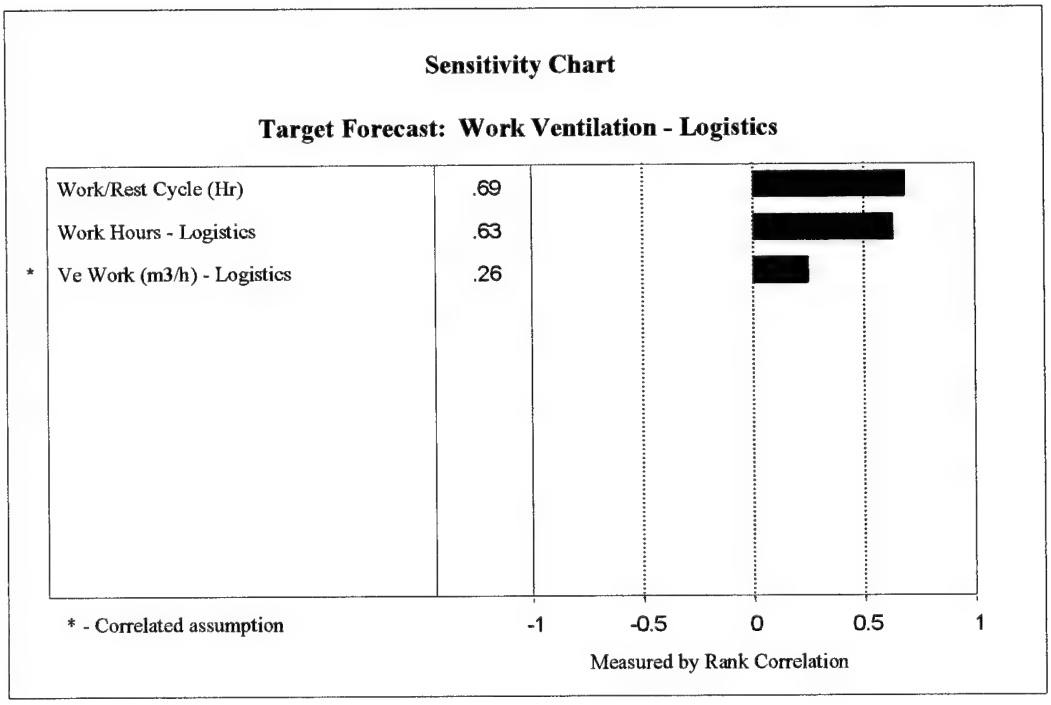

Sensitivity Chart
Target Forecast: Work Ventilation - Armor
Work Rest Cycly (Hours)
Work Hours - Armor
* Ve Work (m3/h) - Armor
.67
.66
.25
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

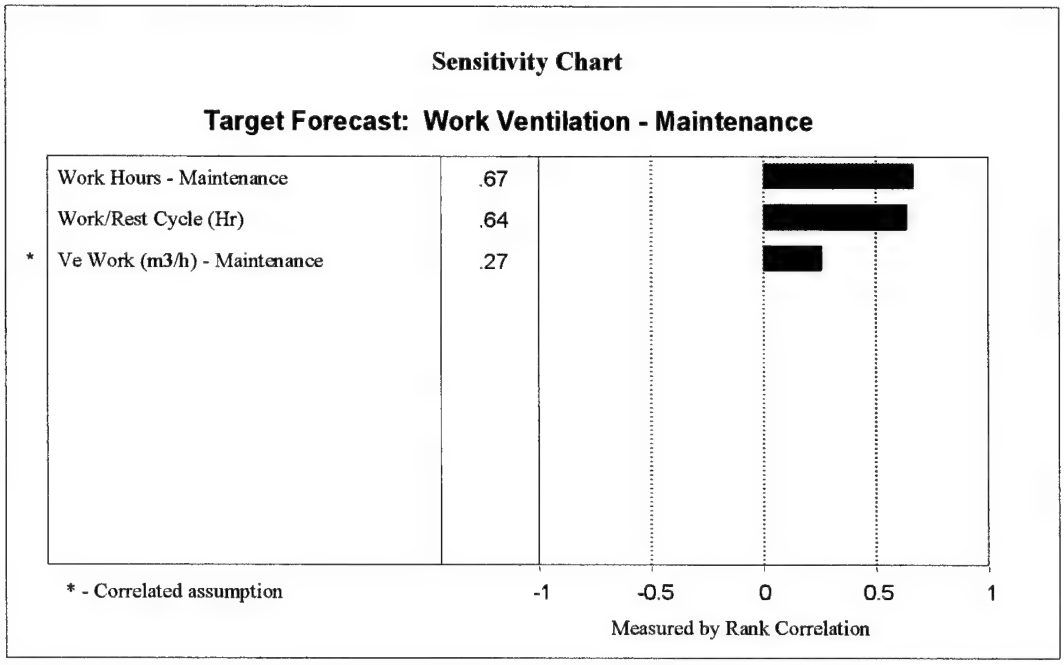

Sensitivity Chart
Target Forecast: Work Ventilation - Artillery
Work Hours - Field Artillery
Work/Rest Cycle (hr)
* Ve Work (m3/h) - Field Artillery
.73
.60
.21
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

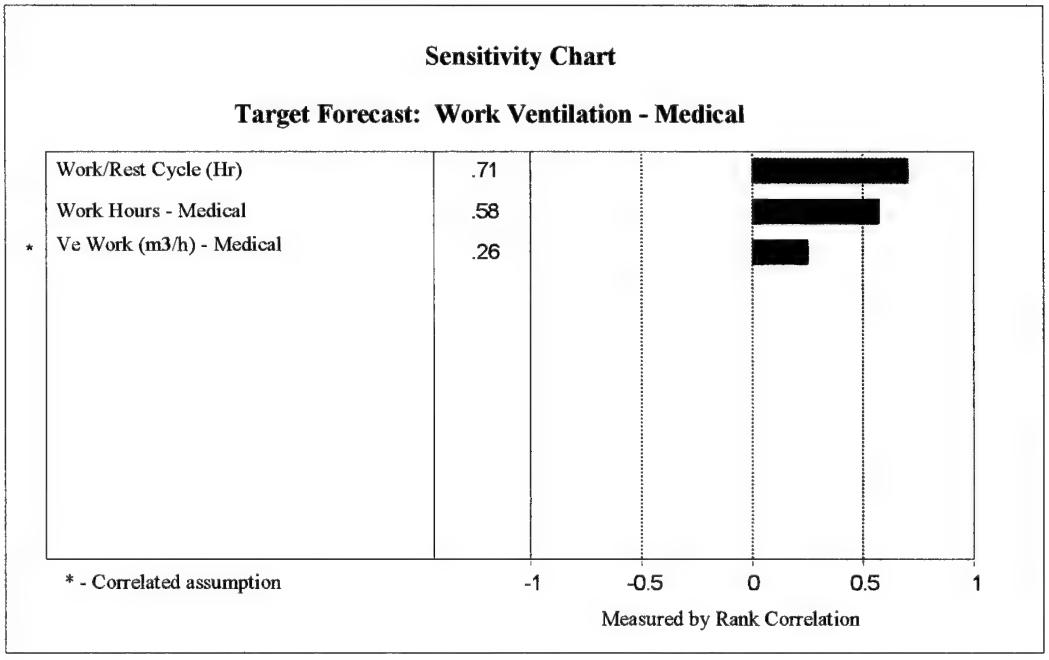

Sensitivity Chart
Target Forecast: Work Ventilation - Aviators
Work/Rest Cycle
Work Hours - Aviators
* Ve Work (m3/h) - Aviators
.69
.64
.26
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

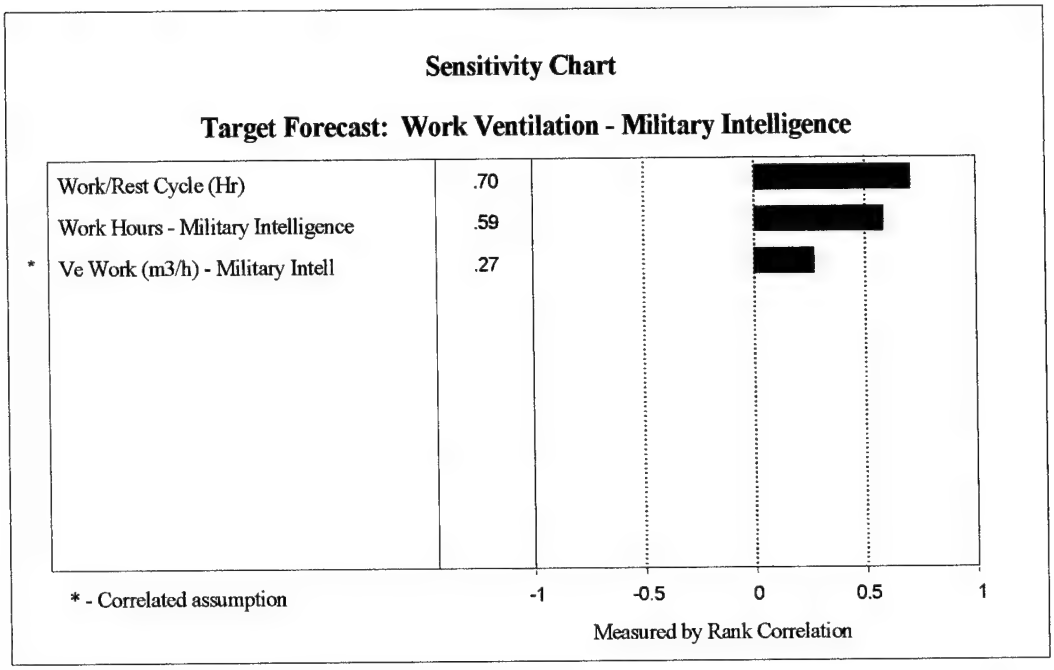

Sensitivity Chart
Target Forecast: Work Ventilation - Engineers
Work Hours - Engineers
Work Rest Cycle (hrs)
* Ve Work (m3/h) - Engineers
.69
.62
.24
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

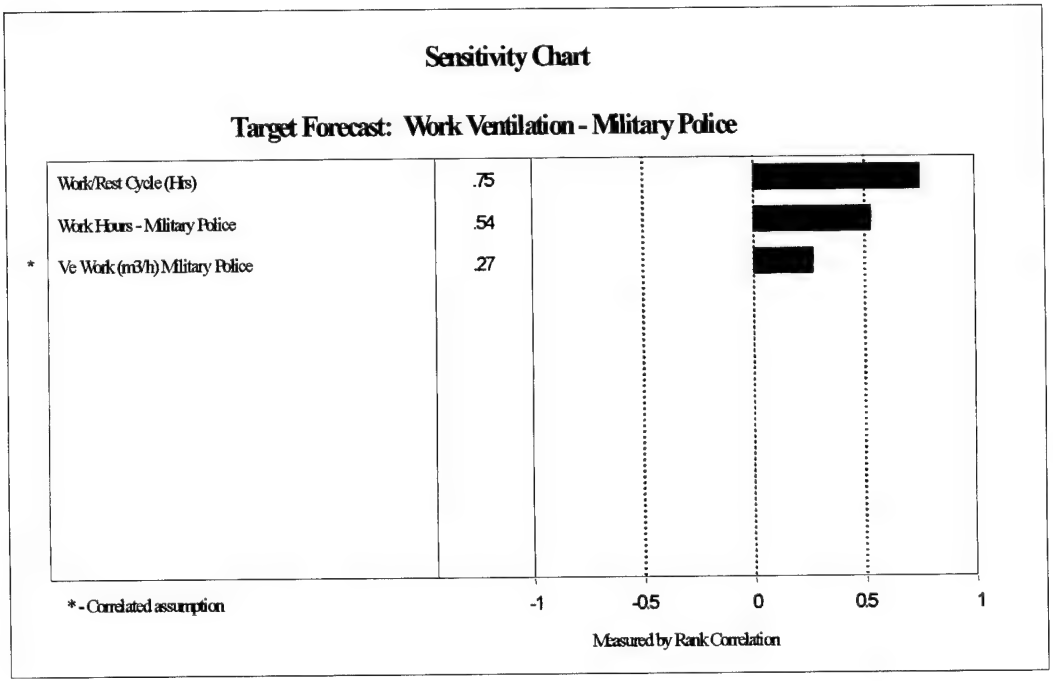

Sensitivity Chart
Target Forecast: Work Ventilation - Infantry
Work Hours - Infantry
Work/Rest Cycle (hr)
* Ve Work (m3/h) - Infantry
.70
.63
.22
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

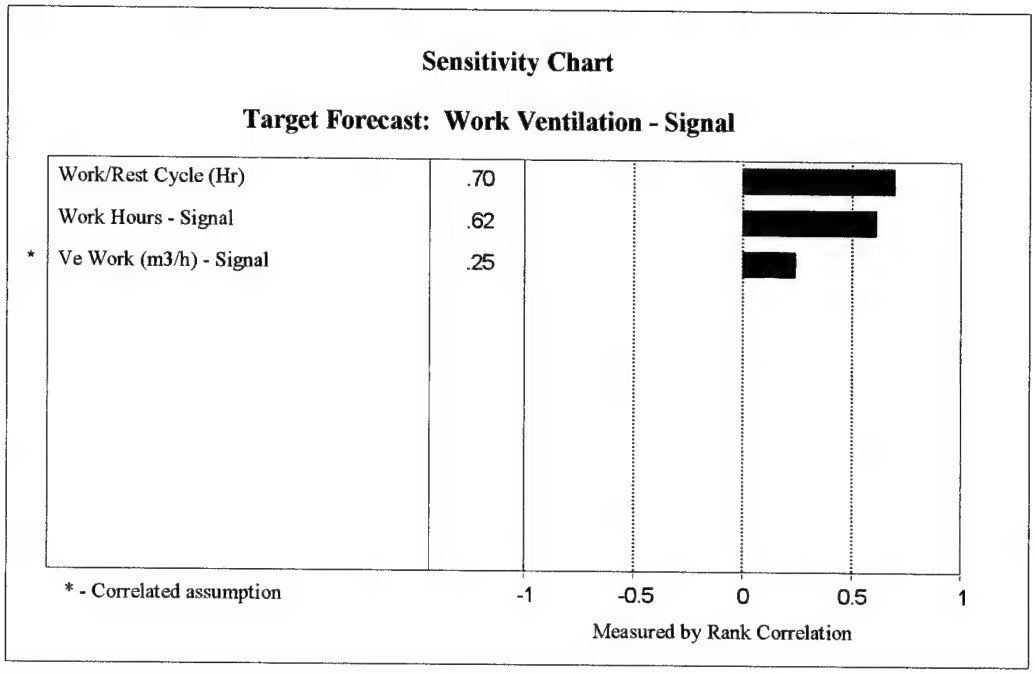

Sensitivity Chart
Target Forecast: Work Ventilation - Logistics
Work/Rest Cycle (Hr)
Work Hours - Logistics
* Ve Work (m3/h) - Logistics
.69
.63
.26
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

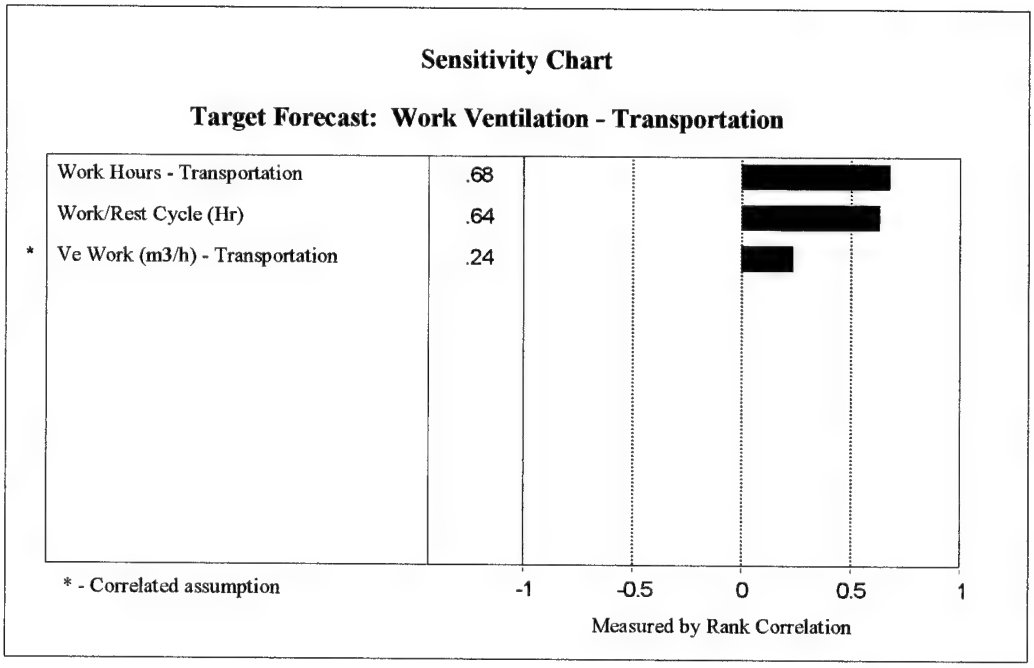

Sensitivity Chart
Target Forecast: Work Ventilation - Maintenance
Work Hours - Maintenance
Work/Rest Cycle (Hr)
* Ve Work (m3/h) - Maintenance
.67
.64
.27
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation


Sensitivity Chart
Target Forecast: Work Ventilation - Medical
Work/Rest Cycle (Hr)
Work Hours - Medical
* Ve Work (m3/h) - Medical
.71
.58
.26
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

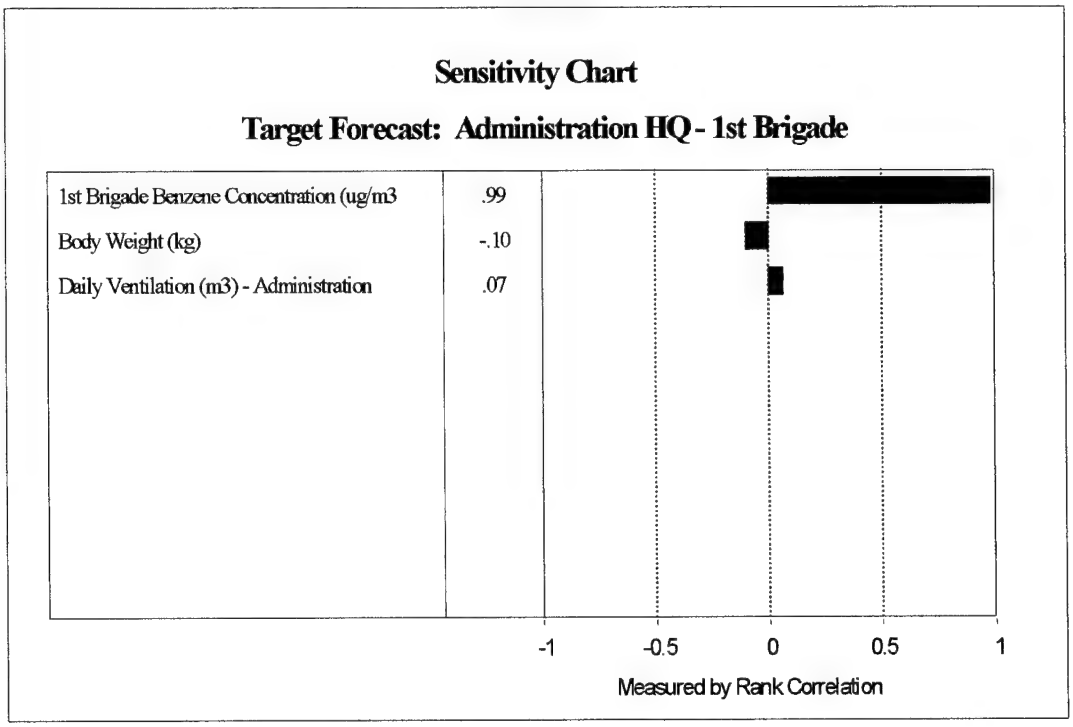

Sensitivity Chart
Target Forecast: Work Ventilation - Military Intelligence
Work/Rest Cycle (Hr)
Work Hours - Military Intelligence
* Ve Work (m3/h) - Military Intell
.70
.59
.27
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

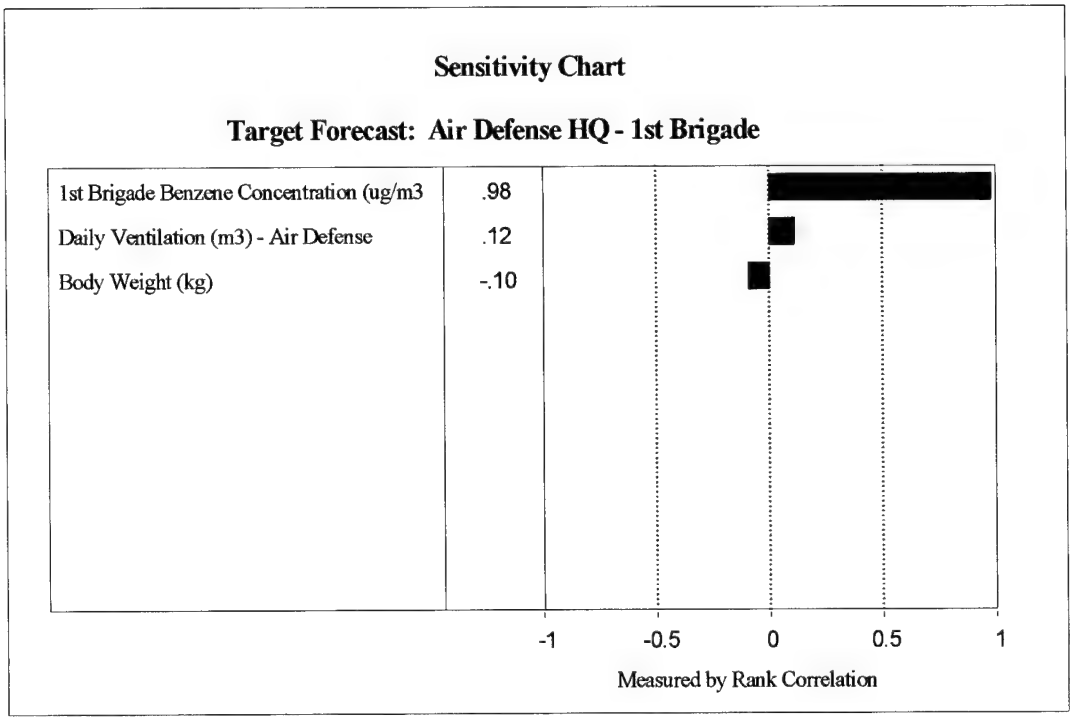

Sensitivity Chart
Target Forecast: Work Ventilation - Military Police
Work/Rest Cycle (Hrs)
Work Hours - Military Police
* Ve Work (m3/h) Military Police
.75
.54
.27
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

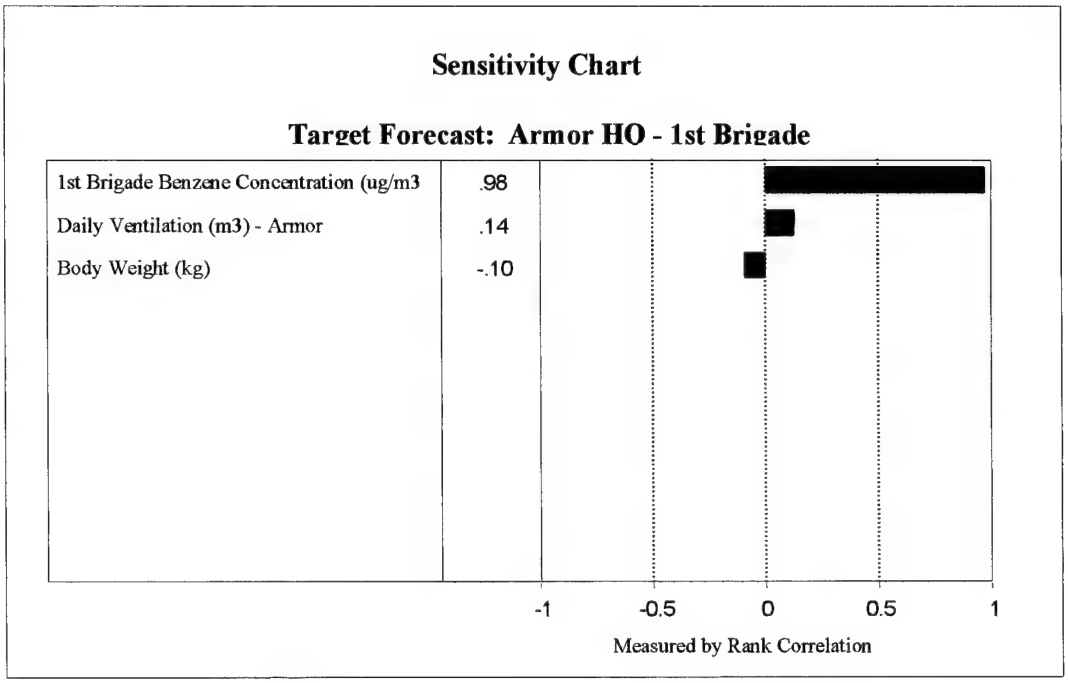

Sensitivity Chart
Target Forecast: Work Ventilation - Signal
Work/Rest Cycle (Hr)
Work Hours - Signal
* Ve Work (m3/h) - Signal
.70
.62
.25
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

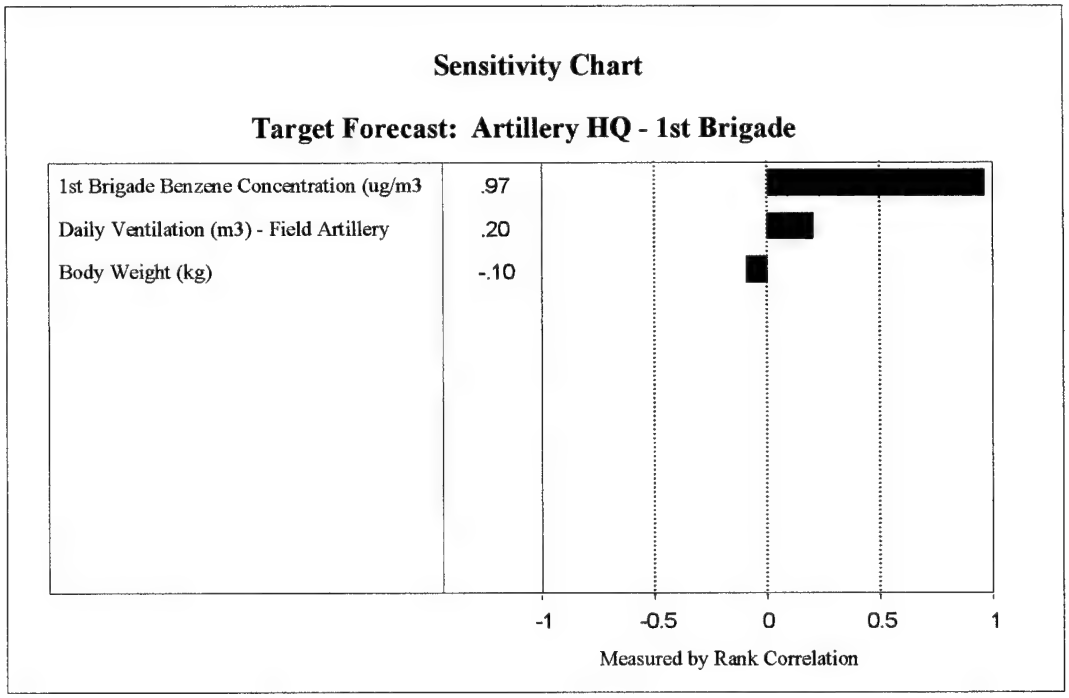

Sensitivity Chart
Target Forecast: Work Ventilation - Transportation
Work Hours - Transportation
Work/Rest Cycle (Hr)
* Ve Work (m3/h) - Transportation
.68
.64
.24
* - Correlated assumption
-1
-0.5
0
0.5
1
Measured by Rank Correlation

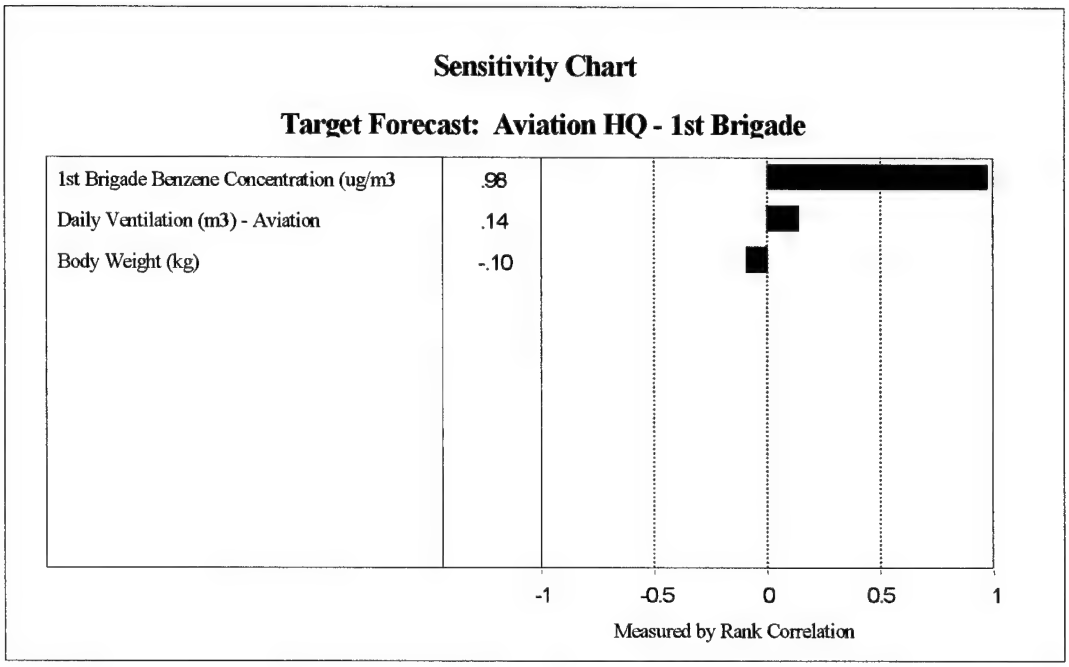
Appendix L: Hazard Quotient Sensitivity Charts

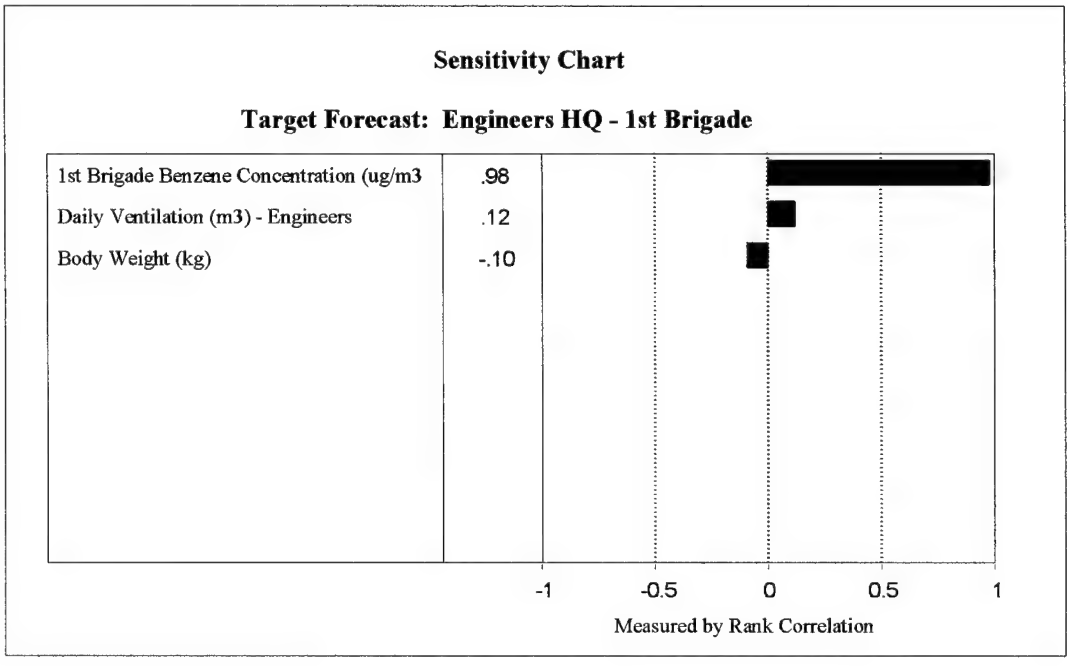


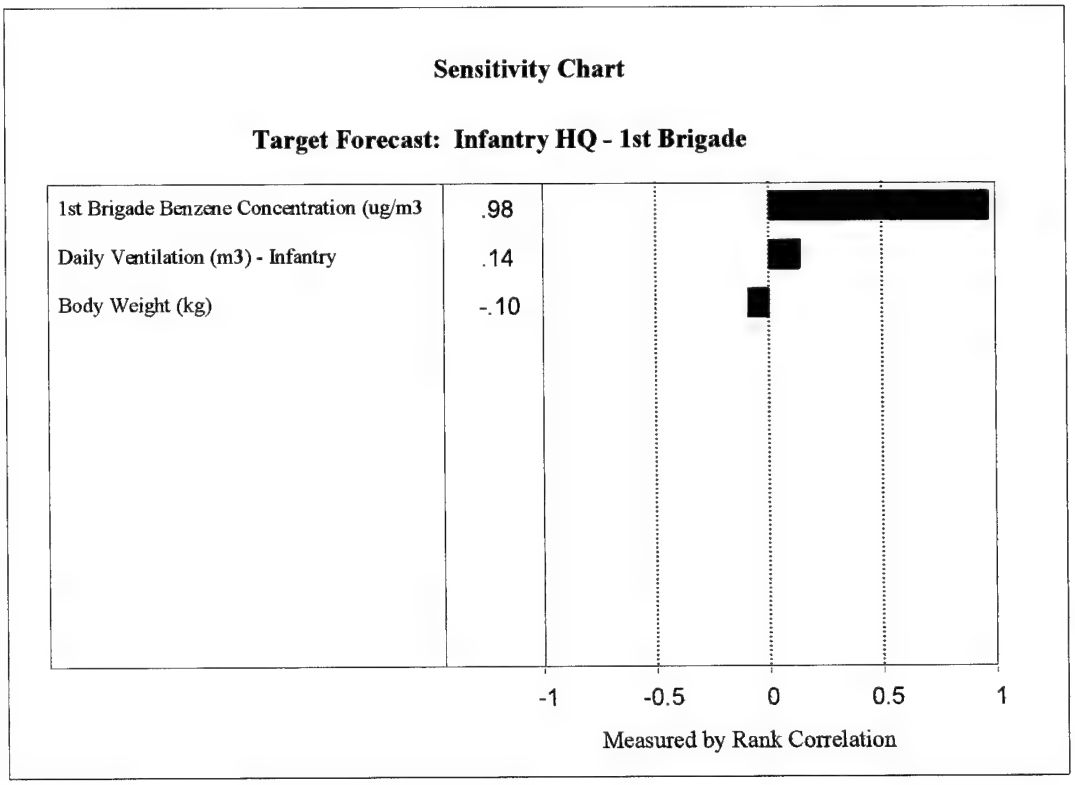


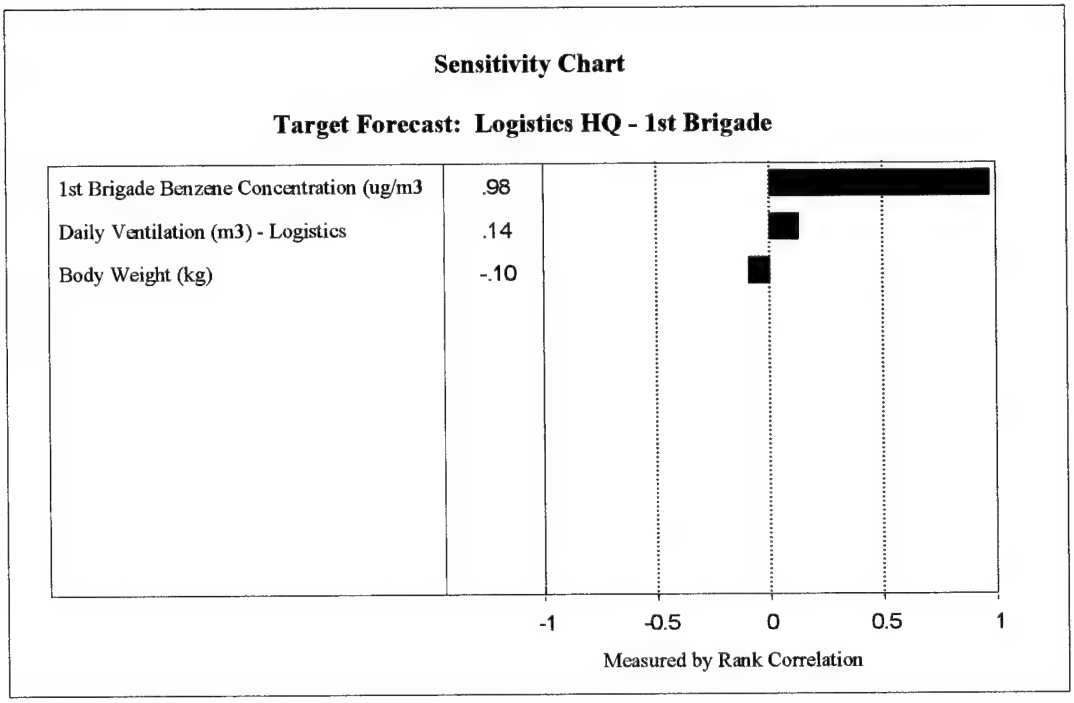

Sensitivity Chart
Target Forecast: Armor HO - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Armor
Body Weight (kg)
.98
.14
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

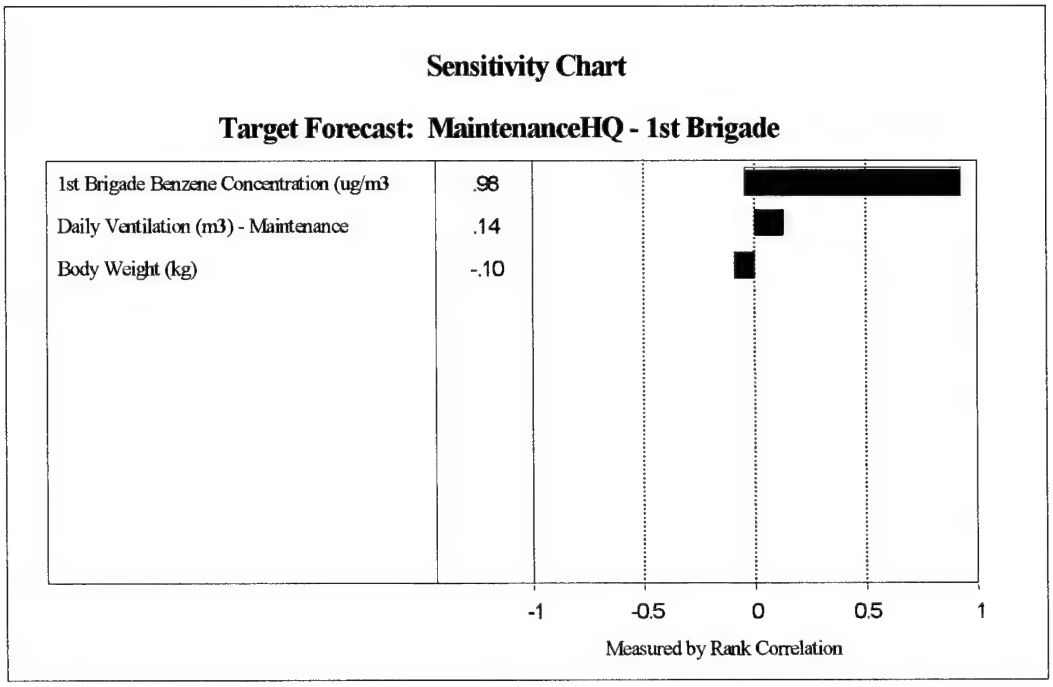

Sensitivity Chart
Target Forecast: Artillery HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Field Artillery
Body Weight (kg)
.97
.20
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

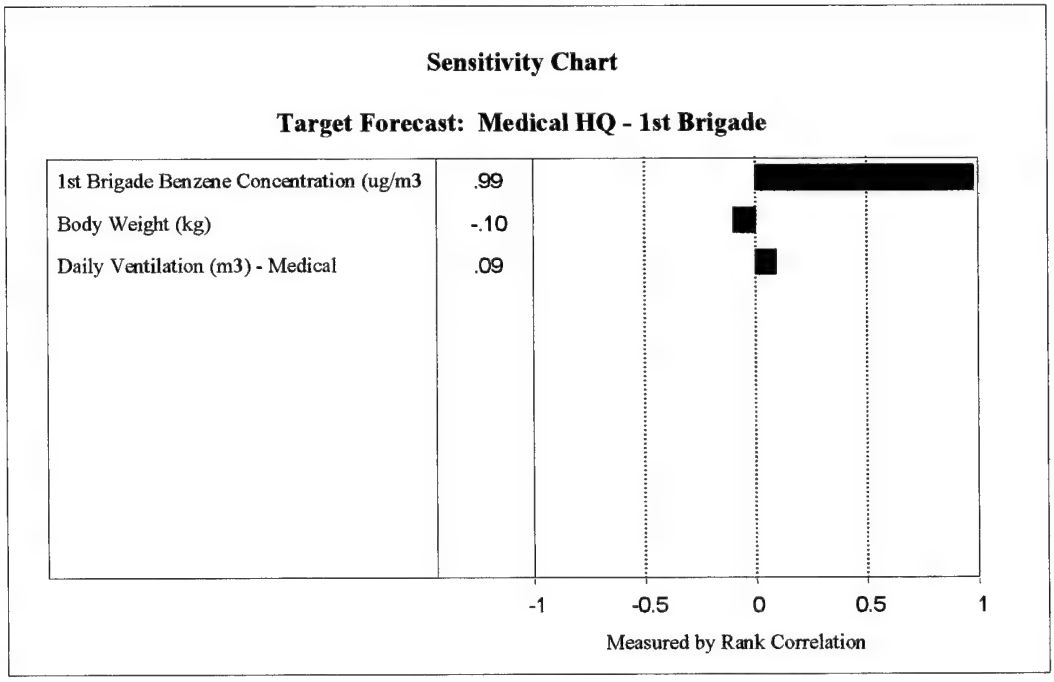

Sensitivity Chart
Target Forecast: Aviation HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Aviation
Body Weight (kg)
.98
.14
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

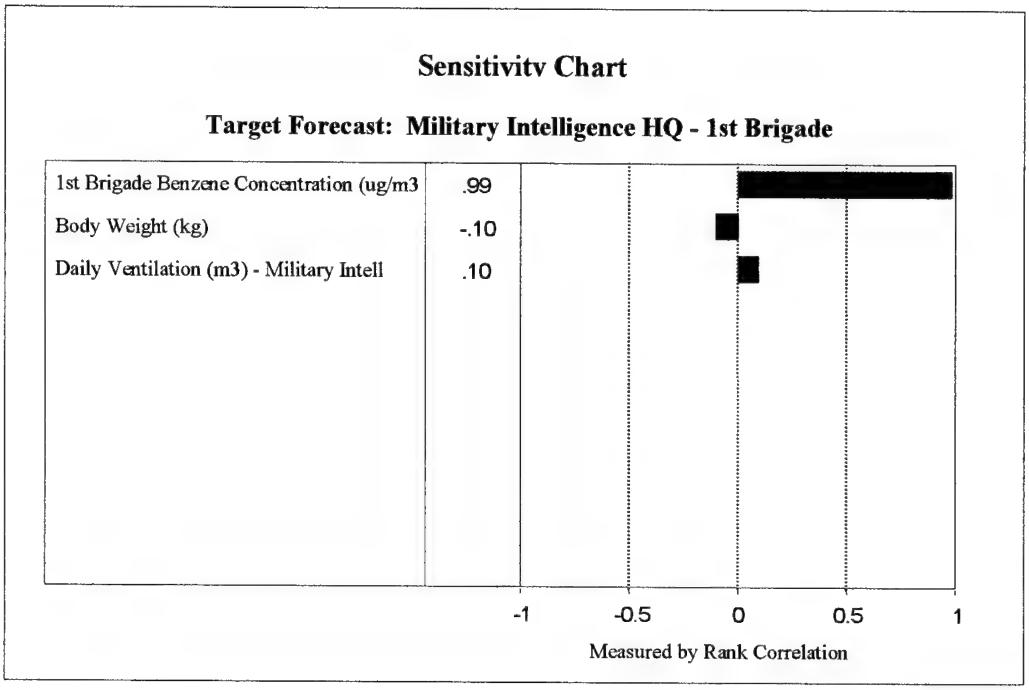

Sensitivity Chart
Target Forecast: Engineers HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Engineers
Body Weight (kg)
.98
.12
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

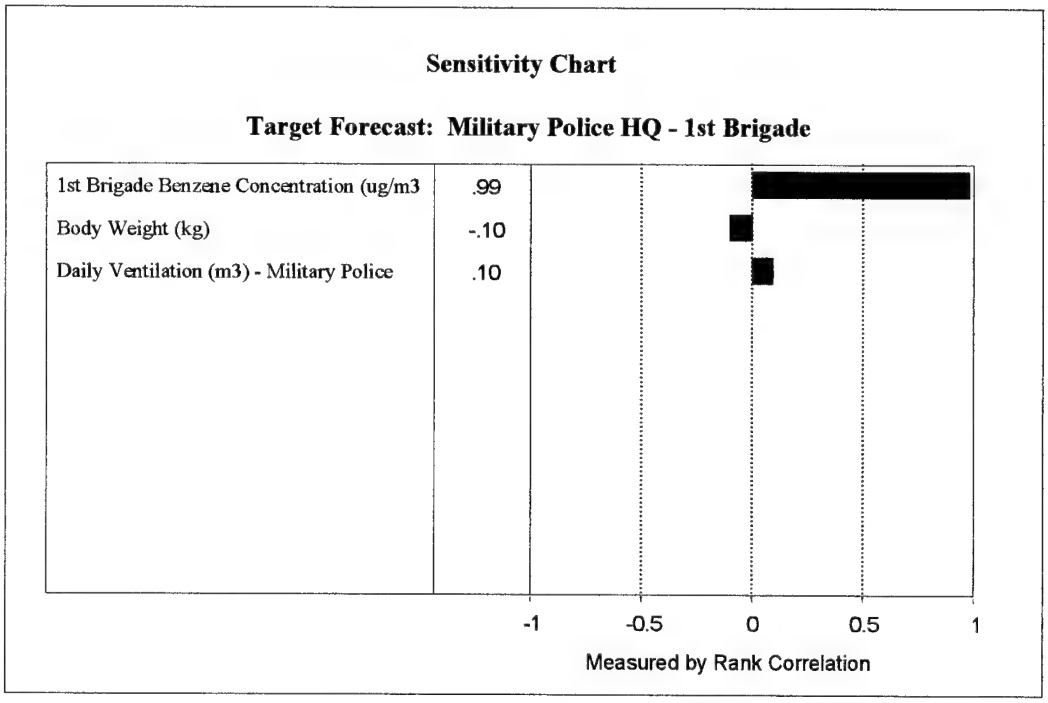

Sensitivity Chart
Target Forecast: Infantry HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Infantry
Body Weight (kg)
.98
.14
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

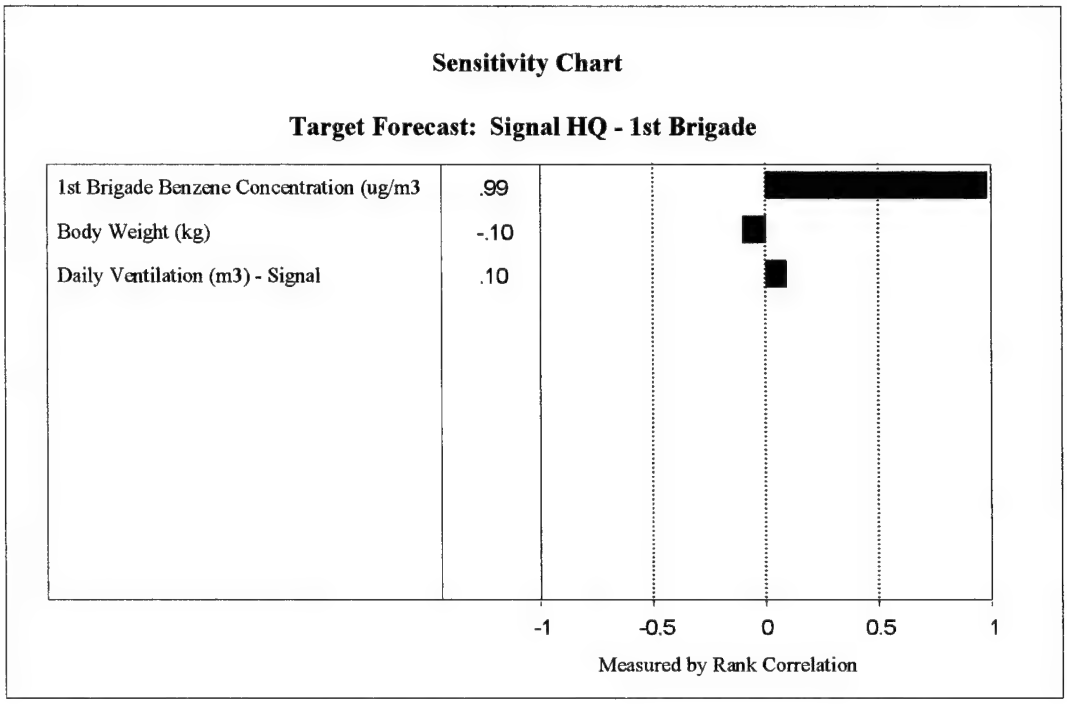

Sensitivity Chart
Target Forecast: Logistics HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Logistics
Body Weight (kg)
.98
.14
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

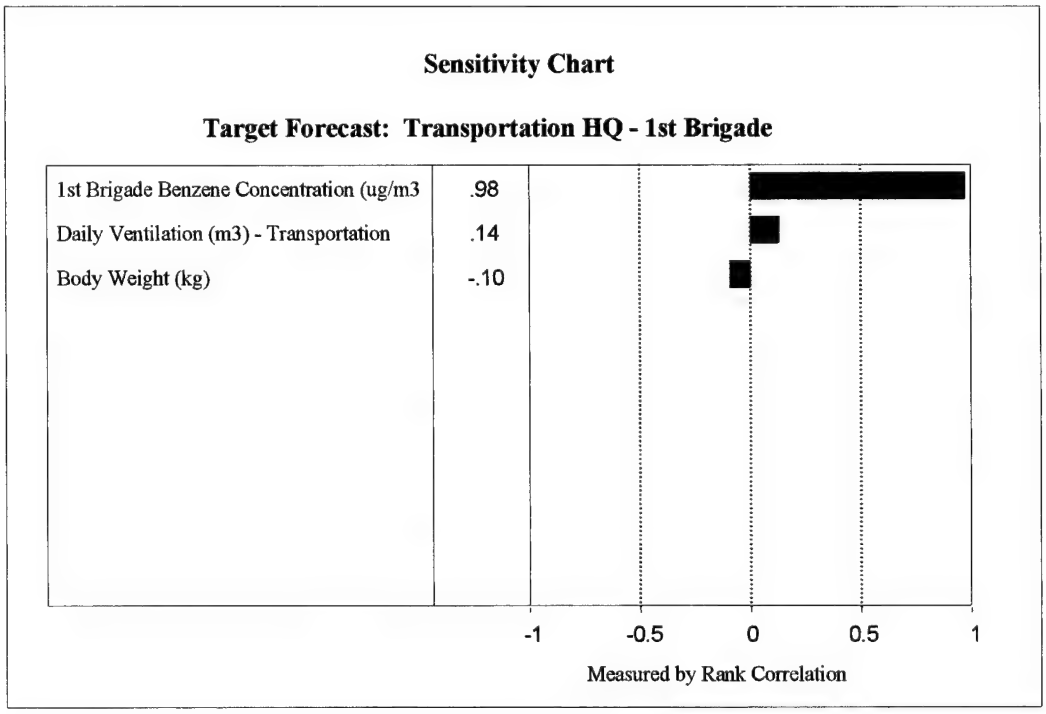

Sensitivity Chart
Target Forecast: MaintenanceHQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Maintenance
Body Weight (kg)
.98
.14
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation


Sensitivity Chart
Target Forecast: Medical HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Body Weight (kg)
Daily Ventilation (m3) - Medical
.99
-.10
.09
-1
-0.5
0
0.5
1
Measured by Rank Correlation


Sensitivity Chart
Target Forecast: Military Intelligence HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Body Weight (kg)
Daily Ventilation (m3) - Military Intell
.99
-.10
.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation


Sensitivity Chart
Target Forecast: Military Police HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Body Weight (kg)
Daily Ventilation (m3) - Military Police
.99
-.10
.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation


Sensitivity Chart
Target Forecast: Signal HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Body Weight (kg)
Daily Ventilation (m3) - Signal
.99
-.10
.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation


Sensitivity Chart
Target Forecast: Transportation HQ - 1st Brigade
1st Brigade Benzene Concentration (ug/m3
Daily Ventilation (m3) - Transportation
Body Weight (kg)
.98
.14
-.10
-1
-0.5
0
0.5
1
Measured by Rank Correlation

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